U. S. DEPARTMENT OF AGRICULTURE,

WEATHER BUREAU.

BULLETIN No. 11.

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# REPORT

OF THE

# INTERNATIONAL METEOROLOGICAL CONGRESS,

HELD AT

CHICAGO, ILL., AUGUST 21-24, 1893,

UNDER THE AUSPICES OF THE

Congress Auxiliary of the World's Columbian Exposition.

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EDITED BY
OLIVER L. FASSIG,
SECRETARY.

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Published by authority of the Secretary of Agriculture.

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1894.

# LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
*Washington, D. C., September* 9, 1893.

SIR: I have the honor to transmit herewith a document entitled "Report of the International Meteorological Congress, held at Chicago, Ill., August 21–24, 1893," and to recommend its publication as Weather Bureau Bulletin No. 11.

Very respectfully,

MARK W. HARRINGTON,
*Chief of Weather Bureau.*

HON. J. STERLING MORTON,
*Secretary of Agriculture.*

# INTRODUCTION.

The Congress Auxiliary of the World's Columbian Exposition was organized by authority and with the support of the Exposition Corporation for the purpose of bringing about a series of conventions of leaders of the various departments of human thought.

The various congresses held their sessions in the Memorial Art Palace in the city of Chicago, from May until October, 1893; those in the Department of Science and Philosophy were assigned to the week commencing August 21. In this department provision was made for a congress on Meteorology, Climatology, and Terrestrial Magnetism. In November, 1892, the President of the Congress Auxiliary, Mr. C. C. Bonney, invited the Chief of the Weather Bureau to organize such a congress. In accordance with this request, I called a conference of gentlemen to consult with me in the arrangement of a programme. The following persons responded to the call and met me at my office on December 21: Professors Cleveland Abbe, F. H. Bigelow, Thomas Russell, C. A. Schott, Lieut. Commodore Richardson Clover, and Mr. O. L. Fassig.

As a final result of the conference the organization indicated on page iv was effected and the programme shown in the Table of Contents was arranged. The papers to be submitted were to be of a strictly scientific character. Authors of papers were to be requested to present in the best manner the present state of our knowledge of the particular branch of the science under consideration.

It was the purpose of the officers of the Congress Auxiliary to print in the English language all papers read at the various conferences, together with an account of the daily proceedings. As this purpose could not be fulfilled by the Auxiliary, and as it was considered desirable to publish the papers of the meteorological congress as soon as practicable, other means of publication had to be sought. The matter was presented to the Secretary of Agriculture, the Hon. J. Sterling Morton, who approved the publication of the papers as a bulletin of the U. S. Weather Bureau.

The failure of the Auxiliary to provide translators for the many papers written in foreign languages caused the labor of translation to devolve upon the chairmen of the sections; to these gentlemen, as well as to Prof. Alexander Ziwet, of the University of Michigan, and to Mr. Robert Seyboth, of the Weather Bureau, I desire to express my obligation for their generous assistance.

MARK W. HARRINGTON,
*Chairman.*

# ORGANIZATION.

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## GENERAL COMMITTEE.

CHAIRMAN.

**Mark W. Harrington,** Chief of U. S. Weather Bureau, Washington, D. C.

VICE-CHAIRMAN.

**Dr. H. C. Frankenfield,** Local Forecast Official, Chicago, Ill.

SECRETARY.

**Oliver L. Fassig,** Librarian, U. S. Weather Bureau, Washington D. C.

MEMBERS OF THE COMMITTEE.

**Prof. Cleveland Abbe,** Weather Bureau, Washington, D. C., Chairman of Section on Theoretical Meteorology.

**Lieut. W. H. Beehler,** U. S. Navy, Hydrographic Office, Washington, D. C., Chairman of Section on Marine Meteorology.

**Prof. F. H. Bigelow,** Weather Bureau, Washington, D. C., Chairman of Section on Atmospheric Electricity and Terrestrial Magnetism.

**Prof. Charles Carpmael,** Director Canadian Meteorological Service, Toronto;
**Mr. A. Lawrence Rotch,** Director of Blue Hill Observatory, Boston, Mass.;
Chairmen of Section on National Weather Services.

**Maj. H. H. C. Dunwoody,** U. S. Army., Weather Bureau, Washington, D. C., Chairman of Section on Agricultural Meteorology.

**Mr. Oliver L. Fassig,** Washington, D. C., Chairman of Section on History and Bibliography.

**Prof. F. E. Nipher,** Washington University, St. Louis, Mo., Chairman of Section on Climatology.

**Prof. Thomas Russell,** Office of U. S. Engineers, Sault Ste. Marie, Mich., Chairman of Section on Rivers and Floods.

**Prof. C. A. Schott,** Coast and Geodetic Survey, Washington, D. C.;
**Mr. H. H. Clayton,** Boston, Mass.;
Chairmen of Section on Instruments and Methods.

## LOCAL COMMITTEE.

(CHICAGO.)

R. Grigsby Chandler.
Elias Colbert.
Ossian Guthrie.
W. S. Jackman.
William S. Seaverns.
Charles B. Thwing.

# MINUTES OF THE PROCEEDINGS.

MEMORIAL ART INSTITUTE,
*Chicago, Ill., Monday, August* 21, 1893.

Monday, August 21, at 10 a. m., the congresses of the Department of Science and Philosophy were formally opened at the Memorial Art Institute with an address of welcome by Mr. C. C. Bonney, President of the Congress Auxiliary of the Columbian Exposition. At the close of this general session, which lasted about one hour, the special congresses met in rooms assigned to them for organization and the reading and discussion of papers.

The Congress on Meteorology, Climatology, and Terrestrial Magnetism met in room No. 31, in which the regular sessions were held daily, from August 21 to August 24.

At 11 a. m., Prof. F. H. Bigelow, in the unavoidable absence of the Chairman, Prof. Mark W. Harrington, opened the Congress, welcoming the members and briefly stating its objects. The Congress had no legislative authority. The main purpose was to collect a series of memoirs prepared by writers of recognized merit in their respective fields of labor, outlining the progress and summarizing the present state of knowledge of the subject treated. These reports are to be printed in full in the English language, and will form a record of great and permanent value in the science of meteorology.

At the conclusion of Prof. Bigelow's remarks Capt. A. P. Pinheiro, Director of the Brazilian Meteorological Service, was called upon to read his paper upon "Storms in the South Atlantic."[1]

Owing to the great number of papers and the absence of authors, the papers were largely read in abstract or by title by the chairmen of the respective sections.

Lieut. Beehler, chairman of the section devoted to marine meteorology, read in abstract the following papers:

"The forecasting of ocean storms and the best method of making such forecasts available," by William Allingham, London.

"The secular change of variation of the mariner's compass," by G. W. Littlehales, Washington, D. C.

"Ocean temperatures and ocean currents," by Lieut. A. Hautreux, Paris.

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[1] As all papers presented to the Congress are printed in full in the following pages, no abstracts are given in the account of the daily proceedings.

"The creation of meteorological observatories on islands scattered over the ocean," by the Prince Sovereign of Monaco.

"The barometer at sea," by T. S. O'Leary, Washington, D. C.

Mr. Fassig, chairman of the section on history and bibliography, presented for reading two papers of his section:

"The meteorological work of the Smithsonian Institution," by the Secretary of the Smithsonian Institution, read by Mr. H. H. Clayton.

"The meteorological work of the office of the Surgeon General, U. S. Army," by Maj. Charles Smart, read by Mr. Fassig.

Prof. Charles Carpmeal followed with the reading of abstracts of the following papers of the section devoted to national services and methods, of which he is one of the chairmen:

"The publication of daily weather maps and bulletins," by Mr. R. H. Scott, of London.

"Can we by automatic records at three selected stations determine the energy of a flash of lightning?" by A. McAdie, of Washington, D. C.

"The utilization of cloud observations in local and general weather predictions," by A. McAdie, of Washington, D. C.

Adjourned, at 1.30 p. m., to meet Tuesday, at 10 a. m.

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TUESDAY, *August* 22, 1893.

The meeting was opened at 10 a. m. by the Chairman, Prof. Mark W. Harrington. The first paper of the day was by Lieut. Beehler on "The meteorological work of the Hydrographic Office of the U. S. Navy." During the reading of this paper, which was devoted largely to the work of Commodore Maury, Lieut. Beehler had placed upon a pedestal, for inspection, a fine bust of the commodore by the sculptor Valentine, of Richmond, Va.

Prof. Lemström, of Helsingfors, moved to hold a preliminary informal session at 10 a. m., Wednesday, to decide upon a programme for the day, the formal session to begin at 10.30 a. m. This was agreed to.

Prof. Mascart, of Paris, then gave a résumé of his paper on "Optical phenomena," referring particularly to the explanation of the white rainbow. He also gave a résumé of M. Chauveau's paper on "Instruments for the observation of atmospheric electricity."

Capt. Pinheiro was called to the chair while Prof. Harrington read his paper on "The history of the daily weather map."

Two papers by Maj. Dunwoody, of the U. S. Weather Bureau, were presented, "Functions of state weather services" and "State weather services of the United States." Upon motion of Mr. Fassig, the delegates to the Convention of Directors of State Weather Services, who were in session in an adjoining room, were invited to be present at

the reading of these papers; the invitation was accepted and the delegates attended in a body. At the close of the readings, Dr. Duncan, of Chicago, made some remarks upon the possibility of predicting epidemics as a result of the development of State weather services.

Adjourned at 2 p. m.

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WEDNESDAY, *August* 23, 1893.

The informal conference agreed upon on the preceding day was held at 10.15 a. m. It was decided to read first the papers whose authors were present; then the chairman of sections were to present the papers of their respective sections of which abstracts had been previously prepared.

At 10.30 the reading of papers was resumed. Prof. Harrington requested Lieut. Beehler to take the chair.

Prof. Carpmael continued the reading of the papers of his section, as follows:

"The prediction of droughts in India," by W. L. Dallas, of Calcutta.

"Plan for the prediction of floods," by M. Babinet, of Paris.

Dr. Veeder, of Lyons, N. Y., read a paper on "An international cipher code for correspondence relating to auroras and magnetic disturbances."

Prof. Bigelow, chairman of the section on atmospheric electricity and terrestrial magnetism, presented the papers of his section, reading some by title, some in abstract. He read at length his paper on "The magnetic action of the sun upon the earth," and it was discussed by those present.

Father Faura, of the Manila Observatory, presented a paper upon "Signs preceding typhoons in the Philippine Islands." Father Faura also laid before the members an elaborate printed report upon terrestrial magnetism in the Philippine Islands, prepared by P. R. Cirera, S. J., Director of the magnetic section of Manila Observatory. Copies of this report were distributed at the close of the session.

Prof. Lemström, of Helsingfors, offered a resolution proposing that the Congress be divided into four sections, in which there should be a discussion as to the most important questions pressing for solution, and that these sections place before the General Congress a recommendation as to the method of carrying on the necessary observations or investigations, the General Congress to discuss such recommendations and take action thereon. The proposition was not agreed to, as such action would be foreign to the purpose of the Congress.

Adjourned at 1.45 p. m.

THURSDAY, *August* 24, 1893.

The meeting was opened as usual in room No. 31, at 10.20 a. m., Lieutenant Beehler in the chair.

The first paper of the day was by Father Denza on "Alpine meteorology," read in abstract by Father Alqué.

Mr. Rotch, associate chairman of the section devoted to national services, read, in abstract, the following papers of his section:

"Meteorological stations and the publication of results of observations," by Dr. J. Hann, of Vienna.

"Present conditions of the weather service—propositions for its improvement," by Dr. W. J. van Bebber, of Berlin.

"The best method of testing weather predictions," by Dr. W. Köppen, of Hamburg.

Prof. Bigelow then took the chair.

In connection with the reading of Dr. van Bebber's paper, Prof. Carpmael suggested that a statement describing the method employed by the U. S. Weather Bureau in forecasting the weather be prepared and sent to Dr. van Bebber to be added to his paper; that he would likewise prepare a statement describing the method employed by the Canadian Service. This would add greatly to the interest and value of Dr. van Bebber's paper when published.

Prof. Lemström then read a paper by Prof. Lindelof, of Helsingfors, upon "The influence of the rotation of the earth on movements at its surface, etc." This was followed by a paper of his own on "The cosmical relations manifested in the simultaneous disturbances of the sun, the aurora, and the terrestrial magnetic field."

The following resolution, offered by Lieut. Beehler, was then read and agreed to:

Recognizing that the members of this Congress do not possess legislative powers, be it resolved that the following statement be added to the official report of the proceedings: In view of the importance of a number of the papers read before the Congress and impressed with the desire of international consideration of certain questions, we request special attention to the following points:

1. International co-operation in observations of auroras.

2. Simultaneous observations at the instant of Greenwich Noon, by all observers on land and at sea independent of, and in addition to, all other observations.

3. Investigation of the earth's magnetic polar field, and exact determination of the period of solar rotation.

Mr. Fassig, chairman of the section on history and bibliography, then read abstracts of the following papers of his section:

"Contribution to the bibliography of meteorology in the fifteenth to the seventeenth centuries," by Dr. Hellmann, Berlin.

"English meteorological literature of the fifteenth to the seventeenth centuries," by Mr. G. J. Symons, London.

"Early individual observers of the weather in the United States," by Mr. A. J. Henry, Washington, D. C.

"Contributions to theoretical meteorology in the United States during the Espy-Redfield period (1830–'55)," by Prof. Wm. M. Davis, Cambridge, Mass.

"Contributions to theoretical meteorology in the United States during the Loomis-Ferrel period (1855–'91," by Prof. Frank Waldo, Princeton, N. J.

"A first attempt toward a bibliography of American contributions to meteorology," by Mr. Oliver L. Fassig, Washington, D. C.

The Congress was then declared adjourned, *sine die*, by the presiding officer, Prof. F. H. Bigelow.

Papers presented to the Congress and not especially referred to in this report were read by title only.

OLIVER L. FASSIG, *Secretary*.

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## PART I.

# PAPERS READ

BEFORE THE

# CHICAGO METEOROLOGICAL CONGRESS.

AUGUST 21-24, 1893.

## SECTION I.

# WEATHER SERVICES AND METHODS.

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### 1.—METEOROLOGICAL STATIONS AND THE PUBLICATION OF RESULTS OF OBSERVATIONS.

Prof. Dr. J. HANN.

#### I.—WHAT ADDITIONAL STATIONS ARE DESIRED FOR METEOROLOGICAL AND FOR CLIMATOLOGICAL PURPOSES?

In many important fields of meteorology the progress of our knowledge depends upon the uniform distribution of the meteorological stations over the earth's surface, so that large districts shall not remain without observing stations.

I will only point out that the important question, whether the mean temperature of the entire earth's surface as well as the quantity of precipitation, etc., undergoes periodic or continual changes, can only be settled when no great part of it remains without stations. Only then shall we be certain that changes in the mean condition of the atmosphere observed at certain stations are not compensated for in a contrary sense on those parts of the earth which lack stations.

The vast extent of the ocean will always be a great obstacle to the investigation of the mean condition and variation of the atmosphere over the whole earth. It is the more important that all oceanic islands should, if possible, have meteorological stations, and this is especially true of the islands of the Pacific. There should be at least uninterrupted records of temperature and rainfall. Much progress latterly has been made in this respect but much remains to be done. The southern oceans, unfortunately, remain almost without stations. Still, by buried thermometers on the islands in the South Pacific, Atlantic, and Indian oceans some temperature determinations may be made, since the determination of the constant earth temperature at suitable points may be employed as a substitute for the estimation of the mean air temperature when there is no prospect of establishing permanent stations.

In the first place, I would insist on the occupation of the oceanic islands by meteorological stations, since here appear the great gaps

in our knowledge of the meteorological conditions of the whole earth's surface.

Referring to certain portions of the globe, it is very important that a ring of meteorological stations surrounding the North Pole should be in constant operation. The Polar region north of Europe and Asia is tolerably well surrounded by the meteorological stations of Russia, Norway, and Denmark, but a permanent station on Nova Zembla is perhaps attainable; a similar station in Spitzbergen remains perhaps only a hope, but it would be of great importance for the determination of the climatological variation of the European frozen ocean.

We have to thank Denmark for the installation of meteorological stations on the coast of west Greenland up to very high latitudes. Thence, further west, there exists a deplorable gap for which, however, the explanation and excuse are not far to seek. Nevertheless, when possible, efforts should be made to establish a permanent meteorological station in Arctic North America between 60° and 165° west from Greenwich, near the seventieth parallel, the further west the better. Point Barrow would be a suitable point for such a permanent station. Perhaps this desideratum for science is already a reality. One or two of the stations in northern Alaska should be in constant operation. In the Antarctic latitudes there can be no question of permanent stations. The most southerly stations in South America and in New Zealand are, therefore, very important as being those in the highest latitudes which it is possible to reach in the southern hemisphere. Much value consequently attaches to the permanency of these stations and to the regular publication of the results of the observations.

In the temperate latitudes of both hemispheres, so far as they are not occupied by the oceans, a sufficient number of stations has generally been provided, and the existing gaps will no doubt shortly be filled. Matters are not so favorable as regards the occupation of the tropical zone by meteorological stations.

The greatest gaps we find in South America. In tropical South America meteorological stations are almost completely lacking, at least in the interior. Some stations in the great Amazon Valley would be of much importance. In Para, Manaos, Teffe (Ega), Tabatinga, and Iquitos, the establishment of meteorological stations would present no impossibility. In the same way stations could be established at some of the capitals of the interior Brazilian states. It is to be regretted that neither in Quito, which possesses an astronomical observatory, nor in Bogota, nor in Lima, are there meteorological stations which publish their observations.[1] In short, tropical South

[1] The new meteorological observatory "Unanue," in Lima, will probably fill this want. —EDITOR.

America remains the *terra incognita* as regards climatological and meteorological data.

Even in tropical Africa, there is improvement in this respect, notwithstanding the fact that tropical South America is occupied by civilized states, which is only true to a limited extent of the interior of Africa. If the Egyptian equatorial province was not, by the shortsighted and foreign policy of a European power, given up to the Mahdists, we should now have continuous meteorological data from Lado and the countries on the banks of Lake Victoria. A good beginning had already been made when barbarity interfered.

Stations in the interior of the Congo States would be very desirable, but we must still wait for them, as well as for stations in the British and German claims in equatorial East Africa. There is, however, every prospect that in German East Africa meteorological stations will be established.

Australia is already partially provided with stations, and, to all appearances, the number will be increased.

For the study of certain interesting questions as to the daily period of wind direction and the daily period of the barometer, stations would be valuable if situated in the midst of a large, even plain. They should be provided with self-recording barometers and anemometers, and the observations should be published *in extenso;* a series of five-year observations would only suffice to answer the proposed questions, viz., daily period of wind direction and amplitude of one diurnal oscillation of the barometer. Those meteorological services possessing such stations are requested to make the fact known.

Stations on tropical plateaux, or better, on high mountains in the tropics, could contribute with advantage to the question of the existence of long periods in the mean air temperature.

Long ago, in the "Zeitschrift für Meteorologie," I stated my opinion that a lofty barometric station in the equatorial regions would give the best explanation of the temperature variation of the stratum of air lying between the station and sea level. The observations of pressure would give a much better indication of this than the thermometer itself, which gives only the local temperature and is subject to many disturbing influences.

The barometer on a mountain is, therefore, to be regarded as a good air thermometer, or at least a kind of differential thermometer when the true height of the barometer is not known. It indicates the temperature of the whole underlying air stratum, or at least the variations. There must also be a base station whose horizontal distance from the high station is so small that no considerable pressure gradient (in a horizontal direction) can be suspected between the two stations during a period of some length, such as a year's mean.

If we designate by $B$ the height of the barometer at the base station, by $b$ that at the high station, by $h$ the difference of height between them, by $T$ the air temperature in absolute measures (that is, $t + 273°$), by $R$ the known constant (for dry air 29.3), the equation—

$$d\,b = d\,B\,\frac{b}{B} + \frac{b\,h}{R\,T^2}\,d\,t \qquad d\,b - d\,B\,\frac{b}{B} = d\,b'$$

is the pressure change at the high station, with the pressure variation at the corresponding place on the earth eliminated, which is only dependent on the temperature and vapor capacity of the air. The true thermic pressure variation at the height $h$ is accordingly, for a station like Quito ($b = 548$ millimeters, $h =$ about 2,850 meters, $t = \frac{1}{2}$ $(27° + 13.5)$, $T$ being therefore 293°, $R$ 29.3),

$$d\,b' = 0.62\,d\,t \text{ or } d\,t = 1.61\,d\,b'$$

If the mean air temperature of the stratum between sea level and Quito changes 1°, the barometric level in Quito alters 0.62 millimeters. Changes of two-tenths of a degree centigrade correspond, therefore, to a pressure change of something more than 0.1 millimeter, which allows of accurate determination in the means of the year.

If, for example, a period corresponding to the sun-spot period exists in the mean air temperature, it must also be equally well shown in the pressure variations of the high station to allow its magnitude to be calculated. While the thermometer only gives the local air temperature of Guayaquil and Quito, for example, which is much influenced by chance circumstances, clouds, precipitation, etc., the barometer furnishes the true air temperature of the whole 2,850 meters of air, as well as the effect produced in the same way by changes in the amount of vapor, that is to say, in a certain degree the "potential" temperature. The mean barometric pressures, therefore, of the tropical high stations give much more precise indications of the variation of the air temperature, and thereby of the solar radiation, than the thermometer itself. In order to derive the full advantages of this method of measuring the air temperature by the barometer, the lower station, where the higher pressure is observed, must not be so far removed from the upper stratum that the relation $d\,b = d\,B\,(b : B)$ holds. Quito, therefore, would not be a good station for this purpose. A permanent station on the Dodabetta Peak, in South India, on the contrary would be very suitable. If the Indian Government would erect a first class observatory on the Dodabetta Peak, in the Nilgiri Hills, science would be much benefited. Such a station would aid meteorology greatly in other directions. Still better would be a permanent station on the Kamerun Peak, in West Africa, but the erection would present much greater difficulties than that on the Dodabetta Peak, which could be easily carried out. (The high station of Nuwara Eliya, 1,902 meters, in Ceylon, if only the barometer correction is

sufficiently constant, I would already place in this category.) Even if the exact altitude above sea level of such a tropical station is unknown, still, by the introduction of an approximate value for $h$ in the above formula, the variation of the lower air stratum can be calculated even if the mean temperature of the whole air stratum cannot. The greatest importance is to be attributed to the constancy of the barometric correction or to the accurate determination of any change therein. Short, but entirely homogeneous, series of pressure means can be used to determine the variations of the mean air temperature.

### II.—SHOULD THE PUBLICATION OF CLIMATIC DATA BE FOR PLACES OR DISTRICTS AS REPRESENTED BY PLACES?

Each observing system should publish, for a certain number of chosen stations, whose number corresponds to the size of the country, thrice-daily observations *in extenso*, and besides these, at certain principal stations, hourly observations, as is in fact done by most of the great European systems.

Besides these, for as many stations as possible, the monthly and annual means should be published according to the international scheme, as has been done in the last reports of the Signal Service. Only in this way can the records of the meteorological stations be made useful generally, and the progress of the science toward efficiency be promoted.

It is to be very much regretted that the observations are not published for many stations, which, from their positions, fill important gaps in our climatological and meteorological knowledge, whereby all the labor which has been given to making the observations is rendered useless.

In other cases the publication is in an entirely unsuitable form, so that the results cannot be used scientifically, or they appear only in local papers which do not reach the specialists.

The installation of stations and the best equipment of them with instruments, their care and reading, are useless, if the results of the observations are not sufficiently made public. Economy in money in the publication of observations must be characterized as the greatest prodigality, since all the outlay expended on the station and the care given to reading the instruments are thus rendered useless. It is to be remembered that the worth of the meteorological data may be increased in a notable way, since for data which only go into the archives, the zeal and care diminish. The observer who sees his observations, or important extracts thereof, printed and distributed, will always try to make them correctly. Criticism of the observations, and its beneficial influence on their value, will be greatly increased by their publication.

In the most liberal form of publication of observations in any

meteorological system, as for example, that of the Central Physical Observatory at St. Petersburg, the cost of printing forms only a small percentage of the cost of the whole observing system, even when the labor of the observer is not considered. The permanent value of the activity of a meteorological system lies in its annual reports, and on these the greatest efforts should be concentrated. The annual reports of the various observing systems of the world form the evidences which seem destined to be laid before future generations as proofs of the present condition of the atmosphere over the earth's surface and for the study and progress of science. Therefore, we owe it to our successors to hand over to them yearly as detailed reports as possible of the meteorological occurrences over the entire globe, in order that with the lapse of time they may be able to answer the question as to the secular variation of the meteorological elements. It is thus always better to publish too much than too little, since what is missed cannot be recovered, and avenges itself by retarding the progress of the science.

The publication of meteorological means for whole districts has no value scientifically. It can, perhaps, for purely practical purposes be used to advantage, but for all scientific work such combined means are wholly unserviceable. It is unnecessary to insist on this, for anyone who has employed meteorological means and data in general for scientific work will agree with me. Neither the stations of a country nor of a district, the instruments and their exposure, nor the local influences at the various stations remain constant long enough to make the means for whole districts appear even tolerably comparable.

The means for districts from different series of years are not comparable with one another and can not be employed to show the changes of the meteorological elements with time. In general such meteorological means and data for whole districts should be confined strictly within the limits to which they belong. They are only to be employed as rough approximations, which, occasionally, may be very useful practically, but are unserviceable from a scientific standpoint.

## 2.—THE PUBLICATION OF DAILY WEATHER MAPS AND BULLETINS.

ROBERT H. SCOTT.

The subject which has been placed before me is one which hardly admits of any very decided treatment, inasmuch as the scale and character of the maps to be published in each country must depend firstly on the amount of money which can be appropriated to the service of preparation and issue of these maps, and secondly on the extent of area which the maps are intended to cover.

It seems to me to be out of place and useless to prescribe for any gentleman, at the head of a meteorological service, what he ought to publish; of that he is a far better judge than any other person, or collection of persons, such as a congress possibly can be. And, as moreover, no congress can possess any executive power to enforce its resolutions, I fail to see the utility of proposing such.

To take a single example. One of the oldest meteorological bulletins in Europe is the "Bulletin Météorologique du Nord." This contains the observations from Denmark, Norway, and Sweden, but no maps of any description. The congress can hardly go so far as to recommend the three gentlemen under whose direction this publication appears, to change its character and adopt the system, say, of the Weather Bureau at Washington. Is there the slightest probability that their respective governments would increase their annual allowances so as to render such a scheme practicable? I say nothing of other offices whose bulletins are even less full than that which I have cited as an instance.

I shall, therefore, confine myself to an account of what the experience of thirty-two years in the preparation of weather reports and of twenty-four years in their issue to the public has shown this office as being well suited to the requirements of the population of the British Islands, some two hundred copies being issued daily to subscribers, in addition to the free issue, as described in our annual reports.

*The daily weather report.*—This consists of a large sheet of royal quarto size, which appears daily, and is accompanied monthly by a sheet containing corrections of occasional errors, and also reports which from any cause have arrived too late for insertion in the daily issue. The bound volume of these reports for the last six months of 1891 contains also tables of mean values of the most important elements of the reports for a period of years—in most cases twenty, but in the case of rainfall for twenty-five years.

The information given in the report is that received by telegraph, and it is conveyed by the use of the International Code, recommended for introduction by the Permanent Committee of the Vienna Congress at its meeting at Utrecht in 1874, and finally adopted by the congress of Rome at its fifth meeting, April 22, 1879. This code provides for the transmission in the morning telegrams of information sufficient for the preparation of two maps, one for the morning of the day on which the telegram is dispatched and one for the previous evening.

The information conveyed in the telegram relates to pressure, temperature, humidity, wind direction and force, weather at the epoch of observation, amount, if any, of rain, or of snow (measured as water), and condition of the sea surface. (It need not be said that the last entry is blank for inland and for sheltered stations.)

From these observations there are two charts prepared for 8 a. m., one showing the barometer, wind, and sea disturbance, (the wind by arrows and the sea disturbance by hatching), the other showing the temperature by isotherms at 10° apart, and the rain in figures, where it exceeds 0.5 inch. Changes in pressure or temperature are printed in words across the face of the respective maps.

The chart for the previous evening is not published by the office except in its weekly weather report, which will be described presently, but a copy is supplied to "The Times" newspaper, and appears in its morning issue of the following day, and so secures a very extensive circulation.

A copy of the 8 a. m. chart is also forwarded to "The Times," and incorporated in the second edition, but the circulation of that edition is not very extensive.

Both of these copies are prepared expressly for "The Times," and at the sole cost of that journal, which for more than thirty years, ever since meteorological telegraphy was organized by Admiral Fitz Roy in 1860, has been conspicuous by the prominence it has given in its columns to meteorological information. In fact, for some years, the entire service for the preparation of these 6 p. m. charts was carried on at the sole cost of "The Times," a fact which affords strong evidence of the public interest in weather intelligence evinced in this country.

*The weekly weather report.*—This was commenced in 1878 at the suggestion of eminent agricultural authorities, in order to supply for the different agricultural districts statements of the temperature and amount of rain for the week, and of their differences from their respective averages. In 1884 this report was materially improved by the insertion of figures illustrating the weekly march of cumulative temperature, that is, of the number of "day degrees" of temperature above or below 42° F. (approximately 6° C.), which, according to the late Alphonse de Candolle, is the degree of temperature at which active vegetable growth may be assumed to commence. A popular explanation of this cumulative temperature will be found in a paper read by me before the International Health Commission in 1874. An explanation of the scientific principles on which the calculation of the values published weekly is based will be found in a paper by Lieut. Gen. R. Strachey, which appeared in the "Quarterly Weather Report" for 1878.

At the present date, 1893, this report contains on the first page, for each of twelve districts:

*For temperature.*—The average and the absolute maximum and minimum. The mean for the week, and its difference from the average for the week.

*For accumulated heat.*—The number of day degrees above and be-

low 42° F. for the week, and their respective differences from the mean, with similar information for the interval elapsed from the beginning of the current year to the last day in the report.

*For rain.*—The number of wet days. The total fall for the week, and its difference from the average, and similar information, as before, for the interval from the beginning of the year.

*For sunshine.*—The number of hours recorded during the week, its percentage of the possible duration, and its difference from the average, with similar data for the interval since the commencement of the year, and general remarks on the weather for the week.

Page 2 gives information for each of the stations, as regards temperature, rain, and sunshine, with differences from averages for the week.

Then follow weather maps for the whole of Europe as far eastward as Odessa, Moscow, and Archangel, giving, respectively, pressure and wind for 8 a. m. and for 6 p. m., and temperature and weather for 8 a. m. only.

Remarks are given for each day, and the report concludes with a table of sunshine values for additional stations in the United Kingdom.

Appendices have, in successive years, appeared in connection with the "Weekly Weather Report," and *inter alia* these have contained figures giving, for each of the districts into which these islands have been divided, the weekly and progressive values of the different elements for each year as far back as 1879.

The daily and weekly weather reports are accompanied by monthly summaries, giving, for calendar months, a brief summary of the weather over the United Kingdom.

This is a brief account of the amount and character of the information which the experience of this office has led it to issue daily, weekly, and monthly, for the use of the public.

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## 3.—FUNCTIONS OF STATE WEATHER SERVICES.

Major H. H. C. DUNWOODY, U. S. A.

State Weather Services are organizations for the collection and dissemination of climatological and other information. They depend almost wholly upon the voluntary co-operation of intelligent and public-spirited citizens, whose individual reports collected at the several central stations form the basis of their publications. These publications are reviews of the prevailing weather conditions published monthly, and bulletins issued weekly during the season of planting, cultivating, and harvesting of crops, giving the more important weather features and their effect upon growing crops from week to

week. Through State weather service organizations, the daily weather forecasts and special warnings of the National Bureau are distributed to large numbers of stations throughout the country.

There are three independent lines of work, each dependent upon its special class of contributors who serve in the capacity of (1) meteorological observers, taking observations of temperature, rainfall and miscellaneous data; (2) crop correspondents, who, during the crop season, render weekly reports of farming operations, the growth, maturing, and harvesting of crops, and the effects of the prevailing weather conditions thereon; (3) the forecast displaymen, who display flags or sound whistle signals representing the weather forecasts of the National Weather Service. It not infrequently happens that one person serves in more than one capacity and sometimes co-operates in all the three distinct lines of work.

In the United States there are less than 175 meteorological stations conducted by the regular paid observers of the Weather Bureau, or about one station for each 22,000 square miles of territory. The utter inadequacy of the data supplied by these stations for purposes of detailed investigation of special localities is therefore plainly apparent, making the State weather service an absolute necessity for the prosecution of such work.

Although the work of collecting voluntary meteorological observations and publishing the results was begun in Iowa as early as 1875, and in Missouri in 1878, the organization of State weather services for the active prosecution of work on the lines previously referred to may be said to have begun in 1881 and 1882, since which time the number of meteorological stations has steadily increased, there being now about 3,000 stations taking and recording meteorological observations daily. With this extensive system it is possible to determine the special climatic features of every section of the country to an extent that would be entirely impossible were it not for the existence of local weather services.

All State weather services issue monthly reviews of the prevailing weather conditions, and many of these publications are issued in elaborate and attractive form, rendering them valuable and interesting. In many of these monthly reviews, besides giving a general discussion of the daily temperature and precipitation, observations are published in detail. While it would be difficult to correctly estimate the great value of this particular line of State weather service work, a more popular feature is the weather-crop service. From the beginning of the crop season until its close, weekly reports of the weather conditions and the effects of the same upon farming operations, the growth of crops, etc., are collected at the several State weather service centers. These weather-crop reports are mailed by the correspondents so as to reach the central station on Tuesday morning, and, as far as

possible, cover the week ending with Monday. Upon receipt they are carefully summarized and a brief discussion of the general conditions prepared, which, with the detailed reports from the several correspondents, forms the State crop bulletin. The official in charge of each State service on Tuesday morning sends a telegraphic summary of the more important features of the week to the National Weather Bureau in Washington.

The entire territory of the country being covered by local services, complete information as to weather and crop conditions is had from every section of the United States. These telegraphic reports are published in full in the National Weather-Crop Bulletin, and, with the charts of temperature and precipitation departures, form the basis of a general discussion of the weather and crop conditions for the whole country.

The charts of temperature and precipitation departures are prepared from the data collected principally from U. S. Weather Bureau stations and serve in a general way to show how the temperature and rainfall of each week compares with the normal of the corresponding period.

This weather-crop service is, with the exception of the general weather forecasts, the most valuable work being done by the National Bureau, and is the most popular feature of State weather service work, being of greatest interest to agriculturists, although the bulletins are eagerly looked for by those interested in other pursuits. To the intelligent farmer it affords a means of supplying accurate and important information as to the condition of crops, enabling him to form reliable estimates as to supply and demand. In some States the editions of the local weather-crop bulletin have already grown to very large proportions, and the demand for the bulletin is constantly increasing. More than 11,000 copies of the Ohio weather-crop bulletin are printed and distributed weekly. As an illustration of the importance of this work, it may be stated that a material change in the condition of the cotton crop in the State of Texas influences the cotton markets of the world; and it is the work of the State weather service that presents weekly impartial and reliable information as to the actual weather and crop conditions prevailing throughout each season.

The publicity given the State and National weather-crop bulletins through the press of the country is so extensive that an accurate estimate of the combined bulletin and newspaper circulation would be difficult of computation. The full text of the National bulletin, including the special telegraphic reports from the various States, is telegraphed each week by the press associations and printed on Wednesday in the large dailies. The agricultural press make a specialty of the bulletin, and some reproduce in their columns the

charts of precipitation and temperature. The patent-sheet papers also find the bulletin an attractive item, and they extensively print the bulletins of the States covered by their circulation. The Missouri bulletin is printed in nearly one hundred patent-sheet papers issued by the Kellogg and Western newspaper companies.

The late Prof. George H. Cook, for several years Director of the New Jersey Weather Service, in the work of organizing the New Jersey service, summarized the importance of the State service as follows:

It will be the means of soon securing better predictions of weather changes and storms.

It will bring the benefits of the National Weather Bureau of the United States into every county participating in the State local organization.

It will soon prepare the State for a system of storm signals displayed from railroad trains that will be widely beneficial to agricultural interests.

It will give to every county the Government standards for temperature, rainfall, wind velocity, humidity, etc., which are sources of useful public information.

It will put within reach of local agricultural societies means of accurate observations which, in the course of years, must be valuable to any locality in the study and adaptation of cereals.

It will bring the science and methods of the National Weather Bureau within the reach of the high schools of the State, offering teachers and pupils alike excellent opportunity to study a wide range of the application of science to foster and protect agricultural industry.

It will lead to the collection of rainfall statistics to enable engineers to better estimate the supply of canals, also the sudden downpours to guard against in laying out sewers in cities. It will lead to a correct knowledge of rainfall over the different watersheds of the State, for the purpose of giving data for supplying the water works of cities, towns, and villages.

It will lead to the forming of reliable meteorological records for use in legal cases.

It will lead to publishing the temperature of summer resorts, drawing attention of outside parties to their desirability as summer residence.

It will lead to a better practice of medicine, when physicians throughout the State can study disease with reliable and accurate meteorological facts by their side—and for sanitary purposes correct meteorological statistics are invaluable to the practitioner in applying preventive remedies for the public good.

The growth and popularity of these services were such that in November, 1885, Gen. W. B. Hazen, Chief Signal Officer, invited the directors of all State weather services to assemble in Washington for the purpose of mutual conference and discussion. Arrangements were accordingly made for a convention of the directors, which met February 24 and 25, 1886. At this conference many important subjects bearing upon State services were discussed looking to improved methods of taking and recording observations, and a general interchange of views regarding State service work was had. Much good resulted from this conference, and a report of its proceedings was published with the Annual Report of the Chief Signal Officer.

A second and more largely attended convention met in Rochester in August, 1892, at which the "American Association of State Weather Services" was formed, the constitution of which provides

for annual meetings, and the convention of 1893 will be held in Chicago in August during the time of the meeting of the Meteorological Congress, August 21–24.

During the past year there have been prepared by many State weather services, for exhibit at the World's Fair, valuable and interesting charts illustrating graphically the special climatic features of the several States. Some of these exhibits have been prepared at much expense of labor and considerable pecuniary cost, and have been very favorably commented upon.

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## 4.—THE PREDICTION OF DROUGHTS IN INDIA.

W. L. DALLAS.

The following gives an account of the method employed in India for the preparation of the seasonal forecasts issued by the India Meteorological Department, the chief object of which is to give warning of the probable occurrence of severe drought in any large area in India.

In northern India there are two distinct periods of rainfall of importance for agricultural operations. The first is the period of the southwest monsoon rains from June to October. They are heaviest in the coast districts and at the foot of the Himalayas, and are most intermittent and irregular in the more interior districts of northern India. The second period is that of the cold weather rains from December to March, when light to moderate showers are received during the passage of feeble cyclonic storms across northern India.

The chief causes of failure of crops in northern India are:

1st. Deficiency of rainfall, more especially in the southwest monsoon period.

2d. Early termination of the southwest monsoon rains.

Under these circumstances the great rice crop in the parts of northeastern India affected withers away and is a more or less complete failure. In northwestern India it prevents the cold weather crops being sown, except in low-lying or irrigated districts.

In southern India, the Deccan, and Burmah, the only period of regular rains of value for the crops is that of the southwest monsoon from May to November or December. In the Deccan and southern India it is moderate in May and June, light from July to September, and moderate to very heavy in October, November, and December.

In these districts the rains may fail more or less completely during a part or whole of the period. The most serious partial failure is when the rainfall of the second maximum (October to December) is light and irregular.

Hence, in northern India the most serious droughts are due to the combination of a more or less complete failure of the southwest monsoon rains followed by a failure of the cold weather rains. In this case both crops, the *kharif* and *rabi*, fail.

In southern India failure of the crops and consequent famine is due to a more or less serious and large failure of the rains of a complete southwest monsoon period. The intensity of the scarcity or famine consequent on the failure of the crops under either of these conditions depends largely upon the character of the previous seasons. If the preceding two or three seasons have been unsatisfactory, so that the accumulated food stocks have been depleted, the famine may be of the most intense character.

The preceding remarks have shown that the most important factor in determining the character of the crops is the rainfall of the southwest monsoon, and hence long period forecasts in India have been chiefly confined to the prevision of the southwest monsoon distribution of rainfall.

These forecasts are usually issued in the first week of June, and attempt to give a rough estimate of the general character of the rainfall of the next four months in the larger provinces of India, and more especially to indicate any area in which there is a strong probability the rainfall will be seriously below the normal, or to point out when there is a probability of unusual delay in the commencement of the rains or of their abnormally early termination in northern or central India.

Rainfall in Europe occurs chiefly during the passage of cyclonic storms, and hence is apparently fortuitous in its occurrence.

In India at least four-fifths of the rainfall occurs as a normal feature of the southwest monsoon circulation. The lower air currents of that circulation advance into India from the adjacent sea areas, determined by the regular periodic pressure and temperature changes in India and central Asia. The circulation is mainly maintained and continued by its internal energy, or rather by that of the energy set free on the condensation of the aqueous vapor brought up in it over India. It varies to some slight degree in intensity from year to year, and its extension also varies in different years, dependent upon the antecedent meteorological conditions.

It is this fact, that the rainfall of this period is due to the prevalence of a massive and steady current, and not to local cyclonic disturbances in a region of irregular winds, that makes it probable long prevision can be successfully attempted and carried out in India.

In order that the attempt to forecast the character and distribution of the monsoon rainfall from the meteorological conditions prevailing anterior to the advance of the rain giving southwest monsoon

currents, it is essential that there should be uniform and direct relations between the former as results and the latter as conditions.

It is immaterial for the purposes of forecasting, whether they are based upon experience or upon theory. It is most satisfactory, of course, that relations emperically obtained should be proved to be in strict accordance with a rational theory.

The following gives a statement of some of the more important uniformities or relations utilized in preparing the long period forecasts in India:

A most important feature is that the general character of the distribution of the rainfall during the southwest monsoon is fairly constant during the whole period, and hence that an area of largely deficient rainfall has usually deficient rainfall throughout the whole season. Similarly for excessive rainfall. The annual reports of the meteorology of India give numerous examples of the persistency of the seasonal characteristics throughout the whole monsoon period. It will suffice to give one example. The southwest monsoon of 1890 gave abundant rain to northern and central India and the north Deccan, and as usually happens when the humid currents are more largely determined to northern India than usual, the rainfall of the same season was in defect in Burmah and southern India. The following gives data:

*Percentage variation of rainfall from normal.*

| District. | 1890. | | | | Total for period. |
|---|---|---|---|---|---|
| | June. | July. | Aug. | Sept. | |
| **Areas of excessive rainfall:** | | | | | |
| Orissa | + 33 | + 10 | + 1 | + 16 | + 11 |
| Assam and east Bengal | + 28 | + 10 | + 13 | − 35 | + 9 |
| Lower Bengal | + 22 | + 10 | − 11 | 0 | + 13 |
| Bihar | + 66 | + 65 | + 31 | − 10 | + 34 |
| Northwestern Provinces and Oudh | + 110 | + 45 | − 8 | + 14 | + 28 |
| Punjab | + 33 | + 28 | + 35 | − 73 | + 15 |
| Central Provinces | − 13 | + 9 | − 3 | + 24 | nil. |
| Hyderabad | + 43 | + 10 | − 7 | + 15 | + 6 |
| Konkan | + 20 | + 27 | + 18 | − 37 | + 12 |
| **Areas of decreased rainfall:** | | | | | |
| Mysore | − 19 | − 12 | − 1 | − 4 | ........ |
| Carnatic | − 15 | − 2 | − 27 | − 49 | ........ |
| Arakan | − 19 | + 24 | − 20 | − 24 | ........ |
| Pegu | − 16 | + 10 | − 10 | − 21 | ........ |
| Tenasserim | − 6 | − 9 | − 27 | 0 | ........ |
| Upper Burmah | − 41 | − 39 | − 30 | − 17 | ........ |

Hence, the steady tendency to increased rainfall in the former areas was as strongly marked as the large deficiency in the latter areas throughout the whole season.

The above example is very interesting on one account, as it shows persistent opposite tendencies and variations in areas of which the meteorological relations to the monsoon currents are more or less opposed or inverse to each other.

The persistent variations in the distribution of the monsoon rain-

fall are related to persistent variations in the strength and extension and other characteristics of the great currents of the period. It will suffice to give one case. The monsoon rainfall was very largely in excess in Burmah in 1891. The following table gives the deflection of the mean winds at three representative stations in that area during each month of the season:

*Westerly deflection*, 1891.

| Station. | June. | July. | Aug. | Sept. |
|---|---|---|---|---|
| | ° | ° | ° | ° |
| Port Blair | +25 | +15 | +18 | +25 |
| Diamond Island | +25 | +8 | +3 | +29 |
| Rangoon | +20 | +28 | +12 | +36 |

The winds at these stations during the southwest monsoon are from directions between south and west, and increased westing ardently indicates a greater determination of the Bay monsoon current to Burmah and Tenasserim than usual.

Again, the monsoon currents were both stronger than usual in 1892 during the period July to September. The following data will show that the increased strength was marked throughout the whole of the period, more especially in the case of the strongest current in that year, viz., the Bengal current:

*Percentage variation of strength.*

| Name of current. | June. | July. | Aug. | Sept. |
|---|---|---|---|---|
| Bengal | +30 | +27 | +15 | +32 |
| Bombay | −30 | +7 | +10 | +15 |

The relations of the variations of the strength and direction of the lower air currents during the southwest monsoon to the rainfall variations require further investigation, but sufficient data have already been accumulated to establish that there are marked differences in the strength and extension of the monsoon currents and in the distribution of the rainfall from year to year, and that these are directly related to each other.

These relations might have been inferred from the fact that the monsoon rainfall is not due to the passage of cyclonic storms, but to the continued prevalence of a steady, strong current charged with vast supplies of aqueous vapor. Assuming that the character of the distribution of the rainfall is fairly persistent throughout each season, and that the rainfall is due to the advance and prevalence of a strong sea current into the Indian land area, it is evident that the extension of this current will be to some degree determined by any abnormal meteorological conditions present before or during its advance. The following gives a brief statement of some of these determining conditions:

(1) Unusually heavy and prolonged snowfall in the Himalayan Mountain area has been shown by Mr. Blanford to exercise a very powerful influence. It modifies the pressure and temperature conditions in northern India, and usually not only retards the commencement of the monsoon but modifies its intensity. The manner in which snowfall modifies the hot weather conditions and the subsequent rains has been investigated and is fairly well known. Abnormally deficient snowfall and its usual correlative, more intense hot weather conditions than usual, on the other hand are found to precede almost invariably stronger and steadier monsoon than usual.

(2) The abnormal pressure conditions established during the hot weather, more especially if they are marked, exercise a large influence in modifying the set of the monsoon currents. The general rule in India is that the hot weather tends to exaggerate and develop local peculiarities of pressure, and the rains to smooth them away. Thus, if the hot weather develop a local deficiency of pressure in any area it tends to become a sink to which the monsoon current is more largely directed than usual, and hence also affects the rainfall in neighboring districts. If, on the other hand, a local excess of pressure is formed, as occasionally happens in Guzerat, northwest Rajputana, etc., it usually accompanies a considerable or large diminution of the rainfall in Rajputana or northwestern India. Much remains to be done to work out fully the influence exerted by high and low abnormal pressure areas in modifying the distribution of the monsoon rainfall, but several useful relations have been established and are used in drawing up these long-period forecasts.

Similarly, the consideration of the temperature conditions of India during the hot weather throws light on the causes of the general and local pressure conditions obtaining before the setting in of the monsoon, and hence enables their probable importance to be estimated.

An important point to be taken into consideration is the relative strength of the two currents, as upon this depends largely the position of the monsoon trough of low pressure, and hence also the mean tracks of the cyclonic storms of the rains and of the heavy rainfall that accompanies these storms. A strong Bombay monsoon tends to displace it northward and a strong Bengal monsoon southward.

Another important point is based on the results of Mr. Blanford's investigations (given in the "Rainfall of India") of the relations between the rainfall variations in different parts of India. He has worked out very fully the areas in which the rainfall variations are usually similar or opposite in character, and the measure of the probability of similar or opposite variations occurring for any given year.

The previous gives a few of the more important principles and facts upon which the forecasts of the distribution of the monsoon rainfall are based.

A consideration of the snowfall data of the cold weather, of the meteorological conditions prevailing during the hot weather, and more especially the character and persistency of the pressure variations, usually enables a rough estimate of the general strength of the monsoon currents and the distribution of the rainfall to be made. This is first done and afterwards a comparison is made with previous years in which similar conditions are known to have obtained. By taking into consideration the actual conditions, the relations established by Mr. Blanford between the rainfall variations in different areas, and the rainfall distribution of previous years of similar meteorological conditions, not only the probable character of the rainfall can be estimated, but also the probability of the occurrence of deficiency or excess of rainfall in any area as dependent upon or resulting from these conditions. This is what is now attempted to be done in the forecasts issued annually in June by the department, and which have had a fair measure of success. For example, a full warning was given in June, 1891, of the drought in Rajputana during the monsoon rains of that year.

It is hardly necessary to point out that the methods employed and sketched above are practically identical with those employed in giving warning of the approach of storms, and I may again point out that these long-period forecasts in India are rendered possible by the peculiar features of the southwest monsoon air motion over India, and by the remarkable persistency of many of the abnormal conditions of the meteorology of that current.

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## 5.—CAN WE BY AUTOMATIC RECORDS AT THREE SELECTED STATIONS DETERMINE THE ENERGY OF A FLASH OF LIGHTNING?

ALEXANDER MCADIE, M. A.

I may begin this paper with an answer in the affirmative. It would be a good plan to have these observations made. The lightning flash has been regarded up to the present time as a thing accomplished, a discharge between the electrified cloud and the earth, over about as soon as seen. It must be a discharge of very high potential because of the length of the spark; and the potential being great the capacity may be small, if, as we have some reason to suppose, the quantity of electricity in a flash is not great. $CV = Q$.

To-day we are beginning to look at a lightning flash from a different point of view. We study the strain in the dielectric, where previously we thought only of the surface electrification; and the *character* of the discharge is now of great importance, and where before we talked of forked, zigzag, and sheet lightning, a classification somewhat like Luke Howard's cloud classification, we talk now of "im-

pulsive rush" discharges, meandering flashes, etc. What we need, and we have in part, is a systematic classification of the electrical discharges in the atmosphere. At one end of the list we might place the impulsive rush discharge, a most intense flash, and at the other the gentle glow discharge which we find so frequently on Pikes Peak and Ben Nevis, and now definitely connect with certain meteorological conditions. Observe, too, that the conditions for the protection of life and property are very different for these different types of discharge. Points fail to be effective under the impulsive rush, while most effective with the glow.

We want, then, to classify our flashes; and to get more accurately at the *character* of the flash, perhaps we should attempt to get at the energy of each particular flash. Dr. Lodge, in his book on "Lightning Rods," in Chapter xv, gives the suggestion of the editor of the "Electrician" that, where thunderstorms are frequent and violent, it might be possible to set up lightning conductors for experimental purposes, and thus accumulate experience concerning their behavior more rapidly than at present. On a preceding page it is also noted how much work could be done at meteorological stations and observatories "in the matter of accurately observing and recording lightning, photographic records, obtained by proper appliances for distinguishing multiple from successive flashes, being, of course, superior to all others. An experimental lightning conductor on a flagstaff near every meteorological observatory would also be a most desirable addition. It need not be associated with danger. A system of fuses or cut-outs, or an east or west steel bar, might be used to record the passage of a flash, and the rod need not be examined until after the cessation of violent disturbances. By having the conductor of different thickness at different parts one could learn what size is really likely to be melted. One could also arrange so as to gain information about side flashes." In the "Philosophical Magazine," August, 1888, Dr. Lodge applies the mathematical expressions for the real resistance and inductance of a conductor under an alternating current to the case of a lightning flash. "An air-condenser with plates of any size separated by a distance $h$ (height of cloud) and charged up to bursting strain ($\frac{1}{2}$ gramme weight per square centimeter; the less strength of rare air is hardly worth bothering about). Let a small portion of this condenser, of area $\pi b^2$, now discharge itself, being separated from the rest after the trap-door and guard-ring manner. A volume of dielectric $\pi b^2 h$ is relieved of strain, and the energy of the spark is $E = \frac{981}{2} \pi b^2 h$ ergs.

The capacity discharged is $S = \frac{K b^2}{4 h}$, and the maximum potential can be put at $110 h$ electrostatic units." He then calculates the

inductance of the circuit $L = h\,(\mu u^2 + \mu_0)$, where $u$ may be a number not very different from 4 or 5, and now knowing $S$ and $L$ proceeds to find the criterion for the discharge to be oscillatory and to determine the rate of alternation. "The discharge will be oscillatory unless the resistance it meets with exceeds a certain critical value, viz.:

$$R_0 = \sqrt{\frac{4\,L}{S}} = \sqrt{\frac{4\,h\,\mu\,u^2}{\frac{K\,b^2}{4\,h}}} = \frac{4\,h\,\mu\,u}{b\sqrt{\mu\,K}} = \frac{4\,h\,u\,\mu\,v}{b}$$

where $v = \frac{1}{\sqrt{(\mu\,K)}} =$ the velocity of light $= \frac{30}{\mu}$;

so the critical resistance is

$$R_0 = 120\,\frac{h}{b}\sqrt{\left(2\log\frac{b}{a} - 1\right)} \text{ ohms."}$$

Suppose $h$ to be a mile (1,609 meters), $b$ 50 meters, and $a$ a millimeter; the critical resistance comes out about 15,000 ohms. When the resistance then falls below this the discharge will be oscillatory. The impedance to a condenser discharge comes out

$$\text{impedance} = 60\,\frac{h}{b}\sqrt{\left(2\log\frac{b}{a} - 1\right)} \text{ ohms.}$$

Or, it is half the critical resistance; it depends almost entirely upon the amount of space magnetized round it; and upon the capacity of the discharging condenser. Magnetic permeability, specific resistance, or even the thickness of the conductor, hardly matter. The length of the conductor does figure.

Now, while we may not erect a conductor a mile high, it is feasible by kites, balloons, or aëroplanes to carry up a wire a millimeter thick some 200 meters. The critical resistance would come out something like 2,000 ohms and the impedance one-half of this, and the frequency constant, $n\,L =$ impedance, something like 3,000,000. Now, the total maximum energy "of a given area of cloud is easily estimated," says Lodge, "by remembering that as soon as the electric tension of the air reaches the limit of about one-half gramme weight per square centimeter disruption occurs; and the energy of the dielectric per cubic centimeter being $\frac{981}{2}$ ergs, per cubic mile it would be $\frac{4.110 \times 10^{19}}{2 \times 3 \times 10^7}$ foot tons, equal to 70,000,000 foot tons. The energy of any ordinary flash can be accounted for by the discharge of a very small portion of charged cloud, for an area of 10 yards square at a height of a mile would give a discharge of over 2,000 foot tons of energy." And for the case we have taken, some 200 meters, we should have from 200 to 300 foot tons, or very roughly in the neighborhood of 1,000 horse power.

With three stations grouped then around a common center, provided with cameras with some type of electrometer and with meteoro-

logical apparatus, we might get first the exact times of occurrence of all visible discharges; and the exact *appearance* of the flashes, *i. e.*, not as referred to one plane which a single camera would give, but the character and *direction* of the flash in space. Many flashes starting from a given point undoubtedly meander, turn and twist upon themselves, and some of the seeming thickenings in single photographs are doubtless points simply of change of direction of flash. Next we would get from the potential fluctuations, as shown on the electrometer records, the exact times and something of the individual strains, and, as I have elsewhere shown, evidences of discharges not visible, and in this way could, from a composite of the records of our three stations, get at a very good approximation of the strains to which our dielectric, the air between the thundercloud and ground, had been subjected; and like a piece of plate armor, when the firing is over, we could examine and locate the places and times of rupture.

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## 6.—THE UTILIZATION OF CLOUD OBSERVATIONS IN LOCAL AND GENERAL WEATHER PREDICTIONS.

Alexander McAdie, M. A.

In our daily work of forecasting weather changes, we have reached the point where we feel the necessity of some knowledge of the conditions of the upper air strata. We map with great success the conditions of the bottom of the aërial ocean in which we live. By the aid of the telegraph we make invaluable synoptic charts. We have excellent ground plans or horizontal sections, but we attempt nothing in the way of vertical sections of the atmosphere. The telegraph is not available; some other agency must be sought for. We, in part, attempt the exploration of the free air by balloons and by mountain observatories, and when aërial navigation is an accomplished fact we shall doubtless have systematic and extensive surveys of the atmosphere. But until that happy time arrives, clouds must remain the best exponents of conditions prevailing at different levels in the atmosphere. They can be made to give us even now, with most crude methods, information concerning the currents at different heights, and indirectly, temperature and moisture conditions. Studied closely and in connection with the surface isobars, isotherms, and winds, the forecaster will find in cloud motions and formations portions of the storm mechanism otherwise hidden from him. For special as well as general forecasting cloud study is important, and I desire to emphasize the need of cloud study at places along the coast. I think that if we had well equipped stations at Capes Fear, Lookout, and Hatteras, with cloud conditions a subject of special attention, we would receive timely warning of the occasional storms that slip in upon us from the seaboard.

Cloud nomenclature and the various methods of cloud measurement do not fall strictly within the limits of this paper. Both topics require special papers. But for the purposes of general forecasting we need, first, a codification of what for want of a name I shall call "cloud laws", *i. e.*, the results of studies of cloud formation and movement; and secondly, some cipher scheme at once flexible and definite that will convey to a distance the *actual* aspect of the sky.

Hildebrandsson in his paper (read before the Royal Meteorological Society, London, February 16, 1887) divides the problem into two sections—how to best study the relation of formation to the physical processes at work; and then the determination of the bearing of these on weather changes. In a footnote he instances the great value and interest a series of cloud observations would have if made by a society of persons specially interested in cloud studies and observing systematically over a large area of country, "keeping strictly to the same detailed nomenclature, *e. g.*, that of Clement Ley."

There can be no question that forecasting would be more certain if we could connect certain types of cloud formation with certain conditions of atmospheric circulation. It being impossible to get the series of observations of the character referred to, I thought that a rough approximation might be made by carefully charting cloud observations made simultaneously by the observers of the Weather Bureau. The classification is that of Luke Howard, and I can only repeat here the remark made in the discussion of Captain Toynbee's paper on cloud names, by Clement Ley, viz.: "Before the dawn of synoptic meteorology, Luke Howard's system filled a need, though it did little to promote inquiry. Since that era it may safely be made the basis of a carefully discriminating and eclectic system of terminology. But any endeavor to restrict ourselves to its use cuts off the possibility of obtaining what becomes more and more necessary, viz., the power of either communicating from distant localities the actual aspect of the sky so that this may be represented graphically or of recording such an aspect, so as to call up in the mind a vivid idea of the observed phenomena; I believe that ten thousand years of observations conducted on Luke Howard's system would give us an absolutely futile record." The language is a little strong, but there is some justification for it. However, it is not altogether an easy task to devise a classification so detailed as to definitely picture up any one of the numerous and often not easily definable sky aspects.

Taking, then, the observations of the Weather Bureau observers, charts were made in the Forecast Room each morning and night, and prove first that it is entirely practicable to construct such cloud maps within the time allotted, and, second, that we can make use of the same in forecasting. The particular point which these bring out is that it is possible to fix with considerable accuracy the storm

center. We need, however, the *velocities* of cloud motion as well as the *directions*. And even in getting direction there is room for great improvement. It should be instrumental, and not, as now, a matter of eye observation. The surface wind is represented by an arrow flying with the wind below the station, the cloud directions by arrows above the station. The velocities could easily be indicated by barbs in the tail of the arrow. Where two or more types of clouds are reported, the uppermost arrow represents the uppermost cloud. I then employed the simple scheme of prolonging the arrow heads of all lower directions and the arrow tails of all upper directions, assuming that in this way we can get at not only the general center of gyratory motion, but if sufficient observations are at hand, the tendency to the formation of any secondary center of gyratory motion.

For general forecasting, therefore, I give it as my opinion, from this practical test, that cloud observations can be used to great advantage. In special forecasting there can be no doubt that clouds should go hand in hand with pressure, temperature, and humidity studies. We should have self-recording nephoscopes, and the diurnal curves directly considered in their relation to the barometer, thermometer, and hygroscope curves. To take the single case of temperature, every forecaster knows that any prediction as to temperature will depend somewhat upon the cloudiness. It is certainly marked in minimum and maximum temperatures. The amplitude of the daily temperature oscillation will be modified by the condition of cloudiness.

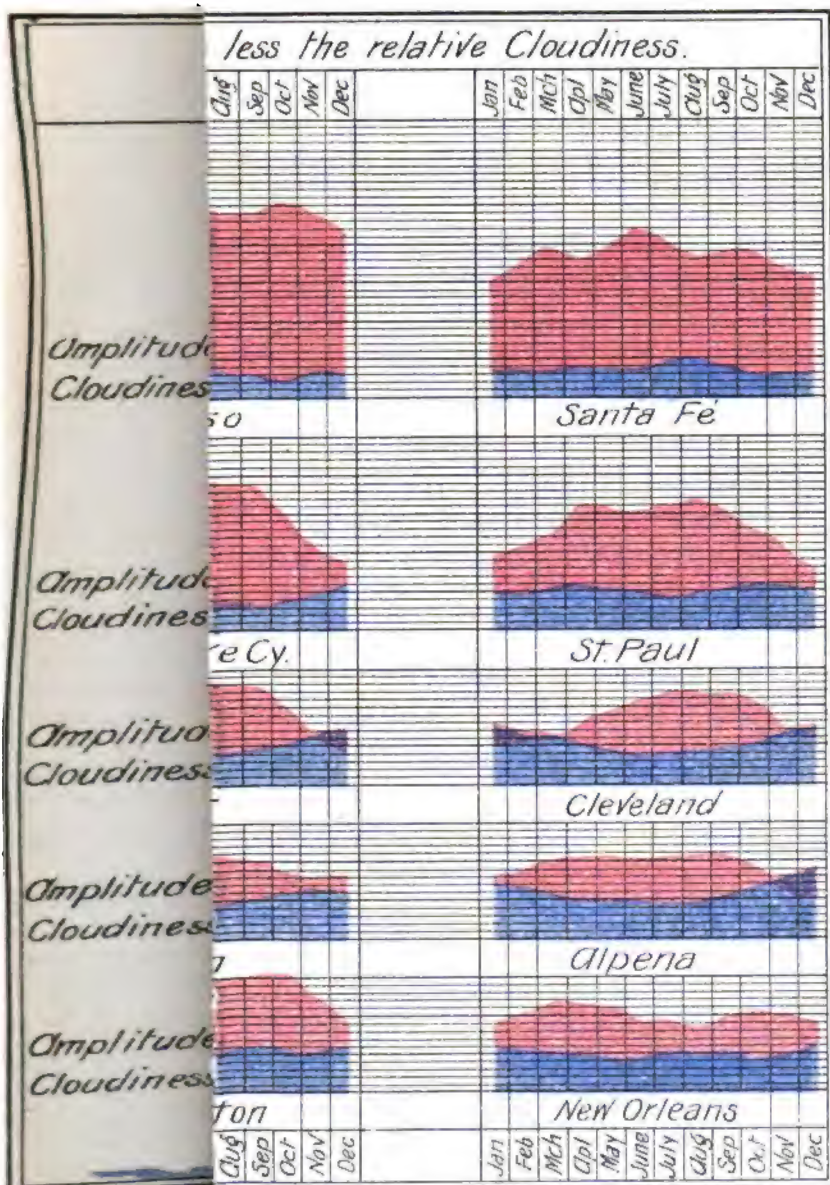
Lamont,[1] E. Quetelet,[2] Rykatschef,[3] Jesse, and Angot have shown for Munich, Brussels, Saint Petersburg, Hamburg, and Paris that the daily amplitude is much greater on clear days than on cloudy days. It seemed to me worth while to practically test this, so I have taken from my paper on "Temperature Corrections" the mean amplitudes, based on some twelve years' observations, and charted with them the mean daily cloudiness for a similar period. The tables show that in the United States the greatest amplitudes are found with the least cloudiness, as was to have been expected. For example, at Winnemucca, El Paso, and Yuma, where, on a scale of 10, the mean annual cloudiness is 3 or less, the values of the amplitude approach 25° F. (13.9° C.); and on the other hand, at Toledo, Cleveland, or Eastport the cloudiness is much greater, about 5, the mean amplitudes are much smaller, about 12° F. (6.7° C.).

[1] Darstellung der Temp.-Verhältnisse, etc.
[2] Mémoire sur la Temp., etc.
[3] La marche diurne de la Temp.

*Temperature amplitudes and mean cloudiness.*

| Station. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Winnemucca, Nev.: | | | | | | | | | | | | |
| °F. | 15.1 | 17.8 | 21.6 | 21.0 | 23.4 | 25.8 | 29.8 | 33.8 | 31.2 | 27.2 | 22.8 | 16.6 |
| °C. | 8.4 | 9.9 | 11.4 | 11.7 | 13.0 | 14.3 | 16.5 | 18.8 | 17.3 | 15.1 | 12.7 | 9.2 |
| Clouds | 4.6 | 4.6 | 3.8 | 4.2 | 3.9 | 3.2 | 1.7 | 1.4 | 1.9 | 2.6 | 3.6 | 4.6 |
| Yuma, Ariz.: | | | | | | | | | | | | |
| °F. | 19.3 | 20.0 | 23.6 | 28.2 | 27.6 | 28.3 | 24.0 | 24.2 | 24.8 | 24.6 | 20.4 | 16.8 |
| °C. | 10.7 | 11.1 | 13.1 | 15.6 | 15.3 | 15.7 | 13.3 | 13.4 | 13.8 | 13.7 | 11.3 | 9.3 |
| Clouds | 2.4 | 2.2 | 2.2 | 1.6 | 1.2 | 0.8 | 1.7 | 2.2 | 1.0 | 1.2 | 1.9 | 2.0 |
| Washington, D.C.: | | | | | | | | | | | | |
| °F. | 8.9 | 10.8 | 11.7 | 14.7 | 15.2 | 14.7 | 14.4 | 14.8 | 14.8 | 15.1 | 11.6 | 9.6 |
| °C. | 4.9 | 6.0 | 6.5 | 8.2 | 8.4 | 8.2 | 8.0 | 8.2 | 8.2 | 8.4 | 6.4 | 5.3 |
| Clouds | 5.9 | 5.6 | 5.4 | 5.3 | 5.0 | 4.9 | 4.6 | 4.9 | 4.7 | 4.7 | 5.1 | 5.6 |
| Philadelphia, Pa.: | | | | | | | | | | | | |
| °F. | 6.8 | 8.0 | 10.0 | 12.6 | 13.6 | 13.0 | 12.8 | 12.1 | 12.0 | 11.2 | 8.4 | 6.9 |
| °C. | 3.8 | 4.4 | 5.6 | 7.0 | 7.6 | 7.2 | 7.1 | 6.7 | 6.7 | 6.2 | 4.7 | 3.8 |
| Clouds | 5.6 | 5.2 | 5.5 | 5.3 | 4.8 | 4.7 | 4.8 | 4.7 | 4.6 | 4.6 | 5.0 | 5.8 |
| Salt Lake City, Utah: | | | | | | | | | | | | |
| °F. | 9.3 | 10.1 | 13.4 | 14.0 | 15.6 | 17.7 | 19.6 | 18.4 | 18.4 | 14.0 | 11.5 | 8.4 |
| °C. | 5.2 | 5.6 | 7.4 | 7.8 | 8.7 | 9.8 | 10.9 | 10.2 | 10.2 | 7.8 | 6.4 | 4.7 |
| Clouds | 5.4 | 5.4 | 5.0 | 5.2 | 4.5 | 3.2 | 3.0 | 3.1 | 2.5 | 3.7 | 4.5 | 5.5 |
| Saint Louis, Mo.: | | | | | | | | | | | | |
| °F. | 8.2 | 9.8 | 11.6 | 13.4 | 13.2 | 13.0 | 14.1 | 14.0 | 14.8 | 13.2 | 9.6 | 7.4 |
| °C. | 4.6 | 5.4 | 6.4 | 7.4 | 7.3 | 7.2 | 7.8 | 7.8 | 8.2 | 7.3 | 5.3 | 4.1 |
| Clouds | 5.3 | 5.3 | 5.4 | 5.0 | 4.9 | 5.0 | 4.2 | 3.8 | 3.7 | 3.8 | 5.2 | 5.8 |
| New Orleans, La.: | | | | | | | | | | | | |
| °F. | 9.0 | 9.6 | 11.2 | 10.4 | 10.8 | 8.4 | 9.0 | 7.6 | 9.2 | 9.6 | 9.3 | 8.6 |
| °C. | 5.0 | 5.3 | 6.2 | 5.8 | 6.0 | 4.7 | 5.0 | 4.2 | 5.1 | 5.3 | 5.2 | 4.8 |
| Clouds | 5.3 | 5.0 | 4.9 | 4.8 | 4.8 | 4.5 | 4.8 | 4.6 | 4.5 | 3.9 | 4.9 | 5.3 |
| Memphis, Tenn.: | | | | | | | | | | | | |
| °F. | 8.9 | 10.0 | 11.8 | 12.4 | 14.2 | 12.6 | 13.6 | 13.8 | 14.2 | 14.2 | 11.7 | 9.2 |
| °C. | 4.9 | 5.6 | 6.6 | 6.9 | 7.9 | 7.0 | 7.6 | 7.7 | 7.9 | 7.9 | 6.5 | 5.1 |
| Clouds | 5.8 | 5.7 | 5.1 | 4.7 | 4.6 | 4.5 | 4.2 | 4.0 | 4.0 | 3.8 | 5.1 | 5.6 |
| Santa Fe, N. Mex.: | | | | | | | | | | | | |
| °F. | 15.4 | 17.0 | 19.4 | 17.4 | 19.5 | 22.0 | 20.0 | 18.2 | 18.7 | 19.0 | 16.5 | 14.8 |
| °C. | 8.6 | 9.4 | 10.8 | 9.7 | 10.8 | 12.2 | 11.1 | 10.1 | 10.4 | 10.6 | 9.2 | 8.2 |
| Clouds | 3.3 | 3.7 | 3.6 | 4.1 | 3.8 | 3.3 | 4.8 | 4.7 | 3.0 | 2.4 | 3.1 | 3.1 |
| Buffalo, N. Y.: | | | | | | | | | | | | |
| °F. | 3.8 | 4.8 | 5.7 | 7.9 | 9.0 | 8.1 | 8.2 | 10.3 | 9.9 | 7.3 | 5.4 | 3.3 |
| °C. | 2.1 | 2.7 | 3.2 | 4.4 | 5.0 | 4.5 | 4.6 | 5.7 | 5.5 | 4.1 | 3.0 | 1.8 |
| Clouds | 7.7 | 6.6 | 6.4 | 5.5 | 5.2 | 4.8 | 3.6 | 4.4 | 5.0 | 6.0 | 7.4 | 8.1 |
| Montgomery, Ala.: | | | | | | | | | | | | |
| °F. | 11.6 | 12.7 | 14.4 | 16.2 | 15.4 | 14.7 | 14.4 | 14.9 | 15.7 | 15.9 | 14.4 | 12.6 |
| °C. | 6.4 | 7.1 | 8.0 | 9.0 | 8.6 | 8.2 | 8.0 | 8.3 | 8.7 | 8.8 | 8.0 | 7.0 |
| Clouds | 6.0 | 5.5 | 4.7 | 4.6 | 4.4 | 5.1 | 4.9 | 4.9 | 4.5 | 4.1 | 4.7 | 5.5 |
| San Diego, Cal.: | | | | | | | | | | | | |
| °F. | 13.6 | 12.4 | 11.1 | 10.4 | 9.8 | 9.4 | 9.5 | 9.9 | 10.5 | 11.2 | 11.9 | 12.5 |
| °C. | 7.6 | 6.9 | 6.2 | 5.8 | 5.4 | 5.2 | 5.3 | 5.5 | 5.8 | 6.2 | 6.6 | 6.9 |
| Clouds | 3.9 | 4.1 | 4.8 | 4.6 | 5.4 | 5.1 | 4.7 | 4.0 | 3.8 | 3.9 | 3.5 | 3.7 |
| San Francisco, Cal.: | | | | | | | | | | | | |
| °F. | 7.0 | 7.2 | 8.0 | 8.6 | 9.4 | 9.5 | 10.1 | 10.2 | 10.7 | 10.2 | 8.0 | 6.0 |
| °C. | 3.9 | 4.0 | 4.4 | 4.8 | 5.2 | 5.3 | 5.6 | 5.7 | 5.9 | 5.7 | 4.4 | 3.3 |
| Clouds | 4.8 | 4.6 | 4.6 | 4.2 | 4.0 | 4.0 | 4.6 | 4.3 | 3.4 | 3.2 | 3.8 | 4.7 |
| Denver, Colo.: | | | | | | | | | | | | |
| °F. | 16.0 | 16.8 | 18.8 | 18.8 | 19.6 | 22.8 | 22.8 | 22.1 | 24.2 | 20.6 | 18.4 | 14.5 |
| °C. | 8.9 | 9.3 | 10.4 | 10.4 | 10.9 | 12.7 | 12.7 | 12.3 | 13.4 | 11.4 | 10.2 | 8.1 |
| Clouds | 3.2 | 3.5 | 4.1 | 4.9 | 4.9 | 3.7 | 4.2 | 4.2 | 3.0 | 3.5 | 3.3 | 3.3 |
| Atlanta, Ga.: | | | | | | | | | | | | |
| °F. | 9.6 | 10.8 | 12.6 | 14.3 | 12.8 | 12.1 | 12.2 | 12.7 | 13.4 | 13.6 | 12.4 | 10.6 |
| °C. | 5.3 | 6.0 | 7.0 | 7.9 | 7.1 | 6.7 | 6.8 | 7.1 | 7.4 | 7.6 | 6.9 | 5.9 |
| Clouds | 5.8 | 5.3 | 4.6 | 4.5 | 4.6 | 5.2 | 4.6 | 5.0 | 4.3 | 4.2 | 4.6 | 5.1 |
| El Paso, Tex.: | | | | | | | | | | | | |
| °F. | 22.8 | 23.3 | 24.6 | 26.2 | 26.6 | 27.6 | 25.0 | 23.8 | 24.1 | 25.6 | 23.8 | 21.6 |
| °C. | 12.7 | 12.9 | 13.7 | 14.5 | 14.8 | 15.3 | 13.9 | 13.2 | 13.4 | 14.2 | 13.2 | 12.0 |
| Clouds | 2.9 | 3.0 | 2.7 | 2.3 | 2.4 | 2.8 | 3.7 | 3.5 | 2.9 | 2.5 | 3.1 | 2.8 |
| Milwaukee, Wis.: | | | | | | | | | | | | |
| °F. | 6.6 | 7.2 | 7.4 | 8.2 | 7.6 | 7.8 | 9.6 | 9.7 | 10.9 | 8.4 | 6.7 | 5.3 |
| °C. | 3.7 | 4.0 | 4.1 | 4.6 | 4.2 | 4.3 | 5.3 | 5.4 | 6.1 | 4.7 | 3.7 | 2.9 |
| Clouds | 6.0 | 5.8 | 6.0 | 5.6 | 5.0 | 5.0 | 4.4 | 4.6 | 4.9 | 5.5 | 6.3 | 6.2 |
| Cheyenne, Wyo.: | | | | | | | | | | | | |
| °F. | 12.6 | 13.4 | 16.8 | 17.9 | 20.7 | 23.8 | 24.2 | 23.6 | 24.4 | 19.2 | 15.6 | 12.1 |
| °C. | 7.0 | 7.4 | 9.3 | 9.9 | 11.5 | 13.2 | 13.4 | 13.1 | 13.5 | 10.7 | 8.7 | 6.7 |
| Clouds | 3.5 | 3.5 | 4.2 | 4.9 | 5.1 | 3.9 | 3.9 | 3.8 | 3.2 | 3.7 | 3.6 | 3.7 |
| Savannah, Ga.: | | | | | | | | | | | | |
| °F. | 11.0 | 12.1 | 13.2 | 11.9 | 11.4 | 11.3 | 10.8 | 9.8 | 11.3 | 12.0 | 12.2 | 12.6 |
| °C. | 6.1 | 6.7 | 7.3 | 6.6 | 6.3 | 6.3 | 6.0 | 5.4 | 6.3 | 6.7 | 6.8 | 7.0 |
| Clouds | 5.0 | 4.8 | 4.3 | 4.2 | 4.2 | 4.9 | 4.8 | 5.0 | 4.8 | 4.0 | 4.5 | 4.6 |
| Chicago, Ill.: | | | | | | | | | | | | |
| °F. | 6.8 | 7.8 | 7.7 | 7.5 | 7.0 | 7.6 | 8.8 | 9.0 | 10.2 | 8.8 | 7.3 | 5.6 |
| °C. | 3.8 | 4.3 | 4.3 | 4.2 | 3.9 | 4.2 | 4.9 | 5.0 | 5.7 | 4.9 | 4.1 | 3.1 |
| Clouds | 5.7 | 5.5 | 5.8 | 5.2 | 4.7 | 4.9 | 3.9 | 3.9 | 4.3 | 5.0 | 5.8 | 6.0 |

Plate                                                  Moddie.




Filly tails.          Polar bands.          Wraith.

No paper upon cloud work would be complete without reference to the work of Ekholm, Hagström, and Hildebrandsson in putting before us the question of cloud measurements. And I must not omit reference to the law of relative directions of lower and upper currents as announced by Ley—high currents coming from a direction to the right of the lower currents, and the higher up the more marked this twist. Or in Ferrel's words "The higher currents of the atmosphere while moving commonly with the highest pressures, in a general way on the right of their course, yet manifest a distinct centrifugal tendency over the areas of low pressure and a centripetal over those of high." It is also not out of place to mention briefly the more prominent of the proposed cloud systems, viz., Luke Howard's, the essay read before the Askesian Society, 1802–1803; Clement Ley's observations; Abercromby and Hildebrandsson's; Wilson-Barker's; Abercromby's; Hildebrandsson and Neumayer's; Dr. Carl Singer's; Köppen and Neumayer's; Dr. Vettin's table of average altitudes, and the work at Blue Hill in this country. As a matter of perhaps more literary than scientific value, I append a list of English cloud designations.

*List of English cloud designations.*

Alto-cirrus, alto-cumulus.
Ark o' the cluds.
Auroral clouds.
Balefrae—bale fire.
Ball clouds, bally.
Banner, banneret.
Bise.
Buddha's rays.
Catstails.
Cirrus, cirro-cumulus, cirro-filum, cirro-nebula, cirro-haze, cirro-stratus, cirro-stripes, cirro-velum.
Cloud, cloud area, cloud bank, cloud ring, cloud ship, cloud wrack, cloud wreath, cloud wraith.
Cormizant.
Corposant.
Coronæ.
Cumulus, cumulo-cirrus, cumulo-nimbus, cumulo-stratus.
Dapple sky.
Dark segment (auroral).
Diablaton.
False cirrus.
Festooned, festooned cumulo-cirrus, festooned cumulus, festooned stratus.
Filly tails.
Fireballs.
Fog bow.
Fracto-cumulus, fracto-nimbus.
Funnel-shape.
Globo-cumulus.
Goats hair.
Helm-bar.
Henscat.
Iridescent.
Leeside.
Luminous.
Mackerel sky, mackerel scales, mackerel back.
Mammato-cumulus.
Mary's ship.
Mare's tails.
Merry dancers (auroral).
Nacreous.
Nightcap.
Nimbus.
Noah's ark.
Nimbo-pallium, nimbo-stratus.
Packet boys.
Pallio-stratus.
Pallium.
Pocky cloud.
Prophet cloud.
Plague cloud.
Polar bands.
Rain balls, rain clouds, rainbow.
Radiation fog.
Rime cloud.
Rocky.
Roll cumulus.
Salmon.
Scud.
Scotch mist.
Saint Clara's fire.
Saint Elmo's fire.
Snow banners.
Spindrift.
Storm cloud.
Snow cloud.
Spectre of Brocken.
Stratus, strato-cirrus, strato-cumulus.
Tablecloth.
Thunder heads, thunder-squall clouds.
Turreted cumulus.
Tornado.
Unraveled.
Watery sky.
Weather lights.
Woolly heads.
Wulst cumulus.
Wool bags.
Wrack.
Wraith.

## 7.—AN INTERNATIONAL CIPHER CODE FOR CORRESPONDENCE RESPECTING THE AURORA AND RELATED CONDITIONS.

Dr. M. A. Veeder.

It is presumed that the assignment of this subject to the writer is intended to call for the results of the experience which he has had in attempting to secure concerted observations of the aurora. The adoption of a special plan of observation or code correspondence respecting such a phenomenon as the aurora presupposes the selection of the points thought to be most important in order that they may be made the subject of special observation and record for purposes of interchange and comparison. The purpose in view in any such case determines the character of the record to be made. If the plan involves nothing more than the preservation of memoranda, such as may happen to be secured incidentally in the ordinary course of meteorological observation, and without reference to the requirements of serious study, it is scarcely worth while to discuss the subject at any great length or offer many suggestions.

All that can be expected, if nothing more than this is to be attempted, is the recording of dates and localities with perhaps some items of description more or less condensed, it may be, by the aid of the systems of classification already in ordinary use which have reference to the presence or absence of arches, streamers, auroral waves, the corona, and the like. Still, the gathering into suitable records and making accessible information not more complete than this, has been the means of affording a knowledge of certain broad features. The relative prevalence of the aurora in different years and its conformity to the records of sun spots and magnetic storms has thus been shown, as has also the predominance of auroras near the equinoxes, and at intervals of about twenty-seven days, corresponding to the time of a synodic rotation of the sun. By such means also the distribution of the aurora in belts surrounding the magnetic poles has become known. If so much is to be learned by the aid of observations that have been for the most part little better than merely desultory, what might not be expected from the elevation of the subject into a special department of research to be undertaken formally and of set purpose?

In the paper on the "Periodic and Non-periodic Fluctuations in Latitude of Storm Tracks," presented by the writer in the Section of Marine Meteorology of this Congress, it is shown that important relations to meteorology may be involved in the operation of the forces concerned in the production of the aurora. This being the case, its behavior is as worthy of careful record as is temperature, pressure, or any other meteorological element.

The experience which the writer has had in this regard has had

reference more particularly to methods of recording observations, and not to any system of code correspondence based thereon. A specimen of the forms which he has employed for securing such records is appended to this paper. The points upon which the greatest possible stress is laid are the giving of the times of observations and of all prominent features, and the noting specifically of verifications of the absence of the aurora as well as its presence, and the recording of frequent estimates of the extent of sky covered. By the aid of such data it becomes possible to attack the questions as to geographical distribution, altitude, coincidence with magnetic perturbations, and the like, positively and directly, and not remotely and inferentially.

Some of the results of this system of observation are indicated in the paper on Storm Tracks, to which reference has been made, and in other notes and articles of similar tenor, and do not need to be rehearsed in the present connection. Suffice it to say that the observations recorded in this precise way are proving to be extremely valuable.

As regards the general descriptions to be given in connection with these observations, it is found that great freedom and fullness in giving details are very desirable. Not unfrequently items of description that would be omitted in a code system of abbreviating and summarizing prove to be of the very highest interest. Further experience is required before it can be fully known what points are of such immediate and practical interest as to justify or require the adoption of so elaborate an arrangement as an international cipher code for their communication. Still, there are indications that something in this line is worth attempting, and that the time is surely coming when a system of correspondence having reference to the whole range of phenomena of which the aurora is the visible expression will be well nigh indispensable for purposes of weather predictions as well as the advancement of general scientific research. It will not be advisable, perhaps, to be too urgent in attempting to bring about such an arrangement prematurely. Not until the facts and principles involved are fully appreciated and recognized by the scientific world generally will the demand for the adoption of an international code system become so emphatic that it can not be disregarded.

The question now is as to the best means of arousing such lively interest most rapidly and effectually. It will contribute somewhat to this end, perhaps, and compel attention to the merits of the case, to describe briefly what would be an ideal system of inter-communication at the present stage of progress of the research respecting the aurora and related conditions.

If there could be brought together upon daily synoptic charts, along with other meteorological data which it is now customary to present in this way, information also in respect to all auroras seen over as

wide an area as possible, and likewise some indication of the extent of prevalence of thunderstorms, together with notes from the magnetic observatories as to the times and extent of any perturbations recorded, and information also as to the geographical distribution of any earth-currents that may have been felt on the telegraph lines, and in addition, some description of the coincident solar conditions on which this class of phenomena evidently depends, any characteristic relations to intensification of storms or changes in the distribution of atmospheric pressure would soon become apparent. Such an arrangement would require simply an extension of the telegraphic code system now in ordinary use for the communication of meteorological data so as to comprise features not heretofore taken into the account.

It is evident that even tentative efforts in this direction would arouse a lively interest, and would certainly stimulate criticism which, whether adverse or favorable, would tend to increase of knowledge, such as could never result from the utter stagnation and neglect to which this class of research has been subjected for extended periods. Such a plan would inevitably bring to a practical test the suggestions that have been made in various quarters recently as to the part which electro-magnetic forces of solar origin play in atmospheric control, and would tend to eliminate errors and crudities which are, to a certain extent, unavoidable in the prosecution of a new line of research, and if there be a residuum of truth it would be shown beyond a peradventure, and its practical value demonstrated.

These suggestions are the outgrowth of the practice which the writer has maintained for many years of journalizing phenomena of this class on a daily record. As the result, the conviction has grown that the principle of electro-magnetic induction of dynamic origin plays a far-reaching part in the economy of the solar system, and that it is concerned in atmospheric control in ways that are only just beginning to be understood. From his point of view, therefore, the scheme of communicating and recording observations above described is well worth trying. How it will impress other minds remains to be seen.

[Copy of form used by the Peary Arctic Expedition in recording auroral phenomena.]

Name and address of observer..........................................Date.................. 189......
Latitude and longitude of station...........................Kind of time used.....................

Observations of the aurora in co-operation with Civil Engineer Peary, U. S. N., in Northern Greenland, are to be entered as follows: *The absence of the aurora* is to be indicated by entering in the proper space the figures showing the minutes of the hour during which such absence was verified by observation. Thus the entry "0–10" in the column headed 7 to 8 p. m. would be understood as showing that observations were made from 7.00 to 7.10 p. m. and that there was no aurora at that instant. If observation is impossible from cloudiness or any cause it will be sufficient to leave the spaces entirely blank. *The presence of the aurora* is to be indicated by writing Aurora in the proper space and giving the exact times and other items under the head of Descriptions. No matter what else may be recorded, it is of the utmost importance to give as accurately as possible the times of any sudden increase or diminution in

brightness of displays, together with estimates of the extent of sky covered and its position relative to the true north. Minute descriptions of the formation of arches, streamers, prismatic colors, and the like, accompanying such variations in the extent of displays, are of interest, but are far less important than that the times should be noted as accurately as possible. A pencil and paper carried in the pocket to note the times, etc., for the purpose of transference to the blanks will be found to be the most convenient plan, and will enable memoranda to be preserved that would otherwise be lost. Even scanty records when kept upon this precise plan may yield most valuable results, for it is impossible to tell in advance of comparison with others what particular entry, whether of the presence or absence of the aurora, may be found to be of the very highest interest. In the present instance the Arctic records will be continuous whenever observation is possible, relays of observers connected with the expedition relieving each other. The records when complete may be returned to M. A. Veeder, Lyons, New York, U. S. A., who will supply blanks and all information desired.

| Date. | 6 to 7 p. m. | 7 to 8 p. m. | 8 to 9 p. m. | 9 to 10 p. m. | 10 to 11 p. m. | 11 to 12 p. m. | 12 to 6 a. m. |
|---|---|---|---|---|---|---|---|
| 1 ........ | ............ | ............ | ............ | ............ | ............ | ............ | ............ |
| 2 ........ | ............ | ............ | ............ | ............ | ............ | ............ | ............ |
| 3 ........ | ............ | ............ | ............ | ............ | ............ | ............ | ............ |
| 4 ........ | ............ | ............ | ............ | ............ | ............ | ............ | ............ |

DESCRIPTIONS.

## 8.—THE BEST METHOD OF TESTING WEATHER PREDICTIONS.

Prof. Dr. W. Köppen.

When weather predictions are issued, naturally there follows the wish of the authors to determine their trustworthiness. If one follows this idea, it is necessary to decide between the various methods of verification. For this purpose the object must correspond with that which is followed in the verification of the predictions.

If it is desired to facilitate a conclusive investigation of the relation between predictions and the weather, both must be dealt with by the same method, as one would investigate the connection between two meteorological factors. It must be pointed out that predictions and the ensuing weather bear the relation to each other of two dependent functions and what conditions this relation implies. It should be shown how different kinds of weather follow different predictions, as we show that different wind directions are followed by different temperatures, etc.

The matter is simplest when one has to deal with predictions concerning which it is doubtful whether they really have a basis or whether they are to be regarded as pure chance predictions, as, for example, when both are based on the moon's phases. It is clear that even chance predictions must give a certain percentage of success. If, however, the real weather be put after the predictions under different headings, it becomes evident whether these figures are due only to

chance or to the knowledge (even if it be occult) of certain laws, since, in the latter case, the weather, according to opposite predictions, would have been sensibly different, while in the first case it would remain the same. The supposition is always that a sufficiently large number of predictions has been included in the verification, since so long as the law of large numbers does not enter, the separation between chance and law is destroyed and no argument is possible, unless it be that the prognosticator is not infallible.

For a better understanding of the above let us take an example from the summer of 1883. There were two kinds of predictions investigated, which we will designate by classes A and B. The second columns give the contents of the predictions:

| | The succeeding weather was— | | |
|---|---|---|---|
| | Warm. | Normal. | Cold. |
| Class A: | Per cent. | Per cent. | Per cent. |
| Warm | 17 | 33 | 50 |
| Cold | 14 | 32 | 54 |
| Class B: | | | |
| Warm | 77 | 15 | 8 |
| Cold | 0 | 5 | 95 |

It is seen that, according to the prediction "A," the real weather remained the same whether the prediction read either warm or cold, but showed a marked contrast with respect to the prediction "B." Now the predictions "A" (made for a month in advance) are true chance predictions, although they excited great surprise and by many are regarded as satisfactory. "B" are synchronous daily predictions of a meteorological institute. In cases of this sort this method is entirely conclusive and sufficient.

Concerning the "B" predictions, this table shows that between them and the following weather there exists an evident relation. In general there can be no question as to the predictions for only twenty-four hours ahead. Even with the most unskilful predictor there would be a general agreement for so short a time. It is to be asked, therefore, how close this connection is, and, indeed, if this relation can be expressed by a single numerical value. Detailed researches on the subject show that, unfortunately, a series of unknown values enters, and that an irreproachable derivation of such a simple number for the expression of the worth of a prediction is impossible—almost as impossible as to estimate the value of a person or a nation by a numerical expression. Such expressions have been proposed, for example, in America in 1884, by Messrs. G. K. Gilbert and C. S. Peirce, but the formulæ given, although ingenious, are one sided, and have not a universal application.

Still less, as a measure of the value of a prediction, can the usual

percentage of success be used in which the influence of chance is neglected and the phenomena are treated without regard to their frequency. If one wishes to have an answer to the question, how often a certain prediction is followed by such and such weather, without regard to the reason, naturally such a calculation of percentage is quite satisfactory, only in the first place we do not know what this can teach us, and secondly, as we shall see directly, from the method of calculation it is largely influenced by the personal interpretation of the verifier. It is, for example, very instructive to know that the 2,803 cases of tornado predictions are so divided that in 2,703 cases, when no tornado was predicted, in only 23 was one observed, in 2,680 cases not, and among the 100 cases where tornadoes were foretold they happened in 28 cases and did not occur in 72.

| | Tornado occurred. *Per cent.* | No tornado. *Per cent.* |
|---|---|---|
| No tornado predicted | 1 | 99 |
| Tornado predicted | 28 | 72 |

From this statement it is seen that the predictor has in the last cases found the tendency to tornado formation. But what good is it when the fraction $\frac{2708}{2803} = 96.61$ is given as the percentage of success of this prediction, a seemingly high number, but which is, nevertheless, inferior to that which would be had if, without trouble, a daily prediction of "no tornado" had been made, for then this number would be $\frac{2752}{2803} = 98.18$ per cent.

The second cause which makes the value of the percentage of success, as usually calculated, seem very small, is the indefinite nature of the fundamental material, and therefore, the consequent impossibility of making the verification comparable.

The determination of what follows a prediction has been generally sought on the basis of the verification of the general character of the day over a large territory, which is fixed by estimation. As to the sincere general wish to get at the truth by this estimation there can be no doubt. Only according to the interpretation of the words and the pessimistic or optimistic tendency of the verifier such estimates must differ greatly; and even when in an institute, by precise instructions they are rendered independent of the person, it will never be possible to introduce such instructions and their interpretation in other institutes, or even to render them so invariable at the same institute that slight changes in their application will not affect the results in an uncontrollable manner. For, in order to determine the influence of each of these rules or usages on the result, comprehensive investigations would be needed, which have not yet been made and for which time would be required that could better be used in the

extension of the basis of weather predictions. Besides, these percentages of success, although as a rule they are understood to be the relation which the successful predictions bear to the whole number, yet they are generally to be considered as the means of the tests which the prediction would give if arranged in various gradations. Thus, most of the German institutes have arranged the predictions according to their results in three grades—the Bavarian Institute, since January, 1882, has used five grades—whose values are 100, 50, and 0, or 100, 75, 50, 25, and 0, as percentages of their entire accuracy, but the arithmetical mean of these numbers has been taken as the percentage of success of the prediction.

For the above reasons, at the *Seewarte* since 1886 the calculation of percentages of success has been abandoned, and in its place statistical summaries in the form already indicated, with as accurate a basis as possible, have been introduced. Also, in the Monthly Weather Review of the Washington Weather Bureau, since January, 1892, the heading "Verifications" has disappeared—a sign that at this great institute the value of these numbers is less considered than formerly.[1]

The method followed by the *Seewarte* carries out these principles:

1. In place of an approximate representation of the whole space and time covered, a precise determination is given for 8 a. m. and 2 p. m. at only three places in the German Empire.

2. For this verification the conditions, as shown by the meteorological observations, are laid down in the following scheme:

| | 8 a. m. | 2 p. m. |
|---|---|---|
| November 4 | *k u l e d* | *n u m s h* |
| November 5 | *w z l w b* | *n z m n r* |

In which place 1 gives the deviation of the temperature from the normal: $k =$ cold (negative deviation greater than 2°); $n =$ normal (deviation 0 to 2°); $w =$ warm (positive deviation greater than 2°). Place 2 gives temperature change in twenty-four hours: $a =$ decrease; $u =$ stationary (change less than 1°); $z =$ increase. Place 3 gives the wind force: $l =$ light (0 to 2), $m =$ moderate (3 to 4), etc. Place 4 gives the wind direction. Place 5 gives the precipitation.

3. As far as the determination of the expression permits, the predictions are also arranged in the same way in classes, and then the agreement of predictions and weather are worked up in comprehensive calculations and put in a tabular form. Further details will be found in the monthly reports of the *Seewarte* from 1886–1891, and especially in a supplement for 1886.

Starting from similar ideas, the storm warnings of the *Seewarte*

[1] The calculation of the percentages of verifications has not been abandoned, but the results instead of being published monthly in the Weather Review are published annually in the Annual Report of the Chief of the Weather Bureau.—EDITOR.

since 1886 differ from those previously verified, and in this way—by a representation of the changes in the wind velocity according to the anemometer indications at the normal observing stations of the *Seewarte* in the six hours preceding and in the thirty-six hours following each storm warning.

The comprehensive tables which have been compiled and published by the *Seewarte* present much material for study which is well consolidated and is thoroughly controllable and comparable. Herein is a precise answer to many questions whose clear comprehension and solution are of great importance for the use of the prediction service. For making up reports to the public, on the contrary, they are too complicated, and demand more knowledge of the difficult questions concerning calculation of probabilities than is often found. The ultimate question, which for practical purposes is preëminent, is, what is the value of weather predictions? Still, this question must remain under all circumstances unsettled, no matter how many or how well founded are the figures cited concerning the measure of the success of the predictions. When, for example, an accuracy of 80 per cent is found for the prediction, one person may consider this percentage as very good, another that the 20 per cent of failure is sufficient to invalidate it, a third may say that he does not find just what he needs in the prediction, the fourth may state that the prediction is worthless if it does not come to him sooner, the fifth may declare the most successful warnings to be useless because he might have predicted just as well the bad weather, and so on. A strict proof of the practical worth of weather predictions and storm warnings is impossible, but the general impression of competent persons must be considered conclusive, and in this combined impression the fulfillment of the prophecy counts for only one, though perhaps the most important, of many circumstances.

If we ask ourselves whether the great working experience which has been gained in weather predictions during twenty years bears a proportionate relation to the results obtained, we must decidedly say no. Among the people there is a widespread belief that the predictor, by a strict and thorough verification of the prediction made by him, must make great progress in his judgment and experience. Were this so, then the verifications would be a duty and worthy of the attention of the meteorologists to whom the task of issuing predictions falls. Really, this task is, as anyone who has prosecuted it long will admit, on the whole a very thankless one, and the time which is expended on it can be much better employed upon meteorological investigations in statistical meteorology upon which the predictions rest. If one will study critically the prediction service, the investigations should at least be as thorough and carried out according to as strict methods as at the *Seewarte*. A report to the public should, in this

case, be as free as possible from numerical data, because figures on this subject are generally misunderstood and really carry only practical convictions in certain directions and only to specialists. For such a report, a statement, as direct and as free from excuses as possible, with concrete examples and the opinion of specialists, is the most convincing and suitable.

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## 9.—PRESENT CONDITION OF THE WEATHER SERVICE—PROPOSITIONS FOR ITS IMPROVEMENT.

Prof. Dr. W. J. VAN BEBBER.

In the states in which weather telegraphy has been used in connection with weather forecasts, either for agriculture or navigation, the experience has been generally that the views on the value of forecasts have been partly overstated and partly understated, and that the hopes which the weather service first inspired have not been fulfilled. The reason for this lies in the fact that our knowledge of the causes of meteorological phenomena is so meager that the practical weather prediction is always accompanied by frequent and great failure, which jeopardize more or less its usefulness, that the progress of practical meteorology is uncommonly slow, and scarcely noticeable, and, finally, that the knowledge of meteorology generally, and especially of the principles underlying prediction, is so slight that such influences as the moon, have, even with learned people, equal or greater value than the prediction issued by scientific institutions.

It is incontestably true, that the predictions of the institutes really have a basis which is capable of further development, and that already in the present state of our knowledge of atmospheric phenomena and their changes, they may be useful for practical vocations, provided that all available means shall be used in their issue and distribution, and that the public understand how to estimate their worth.

On account of the great practical meaning of the forecasts which increases with their accuracy as well as with the extension of the interval of time covered, it appears our duty to strengthen and to spread the fundamental principles in order to accomplish what is possible and to meet the wants of the public in every way.

It seems difficult to put together the success which has been attained in the several states in order to have an adequate survey of the utility of the weather service in these states. True, figures showing the percentage of success have been published by the various Institutes, but these have for the estimation of the real worth and utility of weather prediction but very little value, since in the verification a series of circumstances must be considered which influence the final result greatly. Chief among these are the probability of

the occurrence of a weather phenomenon, or chance, also the persistent tendency of the weather, and finally, the greater or less use which can be derived from the forecast. So long as all these points do not find recognition in the verification, the percentages of success, no matter how scientific and rigorous the verifications may be, are only of secondary importance, and can not, as may easily be shown, be regarded as proper criteria for the success or failure of the prediction. But, in the efforts to take account of all these circumstances we come to the difficulty, which appears the more insurmountable and the greater, that much must always be left to arbitrary decision.

Upon these points a detailed report of Prof. Dr. Köppen is presented to the Congress, so that further discussion is unnecessary.[1]

The best, and up to now, the only correct and definite scale for the utility of prediction is the judgment of the public and of that portion of the public which is most interested in the predictions, that is to say, the coast inhabitants and the agriculturists, who, from their vocations, are most dependent upon wind and weather. As regards the first class, opinions have been given in the United States, by the London Meteorological Office, and by the *Deutsche Seewarte*. According to these the coast dwellers regard the storm warnings, in spite of the frequent failures, as a desirable arrangement. As a further confirmation of the utility of the storm warnings I would add the fact that on the German coast the Provincial authorities and some private persons have erected and maintained signal stations at their own cost, where those of the Government were not sufficient.

The judgment of the public on weather predictions for agricultural and industrial purposes differs generally so much that it appears impossible at present to draw valid conclusions as to the value of the same; however, I have always had the experience, as is the case elsewhere, that those persons who have a direct interest in the predictions place a greater value upon them than those who regard the thing as more indifferent to their professions.

On the whole, it can be affirmed that even in the present state of weather prediction great use can be derived for practical life, so that the practice of it by Institutions ought not to be given up or curtailed. Therefore it appears a pressing necessity to employ all suitable means to advance weather prophecy, such as (relating to weather telegraphy) the speedy collection and distribution of the reports and (regarding prediction) the application of accumulated experience which can add to the progress of the service, that is to say, the extension of the predictions.

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[1] See Section I, p. 30. See, also, Van Bebber: "Die Ergebnisse der Wetterprognosen," *Monatsbericht der Deutschen Seewarte*, 1886 +. "Ergebnisse der Sturmwarnungen," *ib.*, 1889 +, and *Das Wetter*, 1889, p. 268. *Monatliche Uebersicht der Witterung*, Hamburg, 1882. *Monatsbericht der Seewarte*, Hamburg, 1889.

The greatest, and also the best organized, system of weather telegraphy is in the United States, so that we may take this as a model for the other countries. In Europe there must be radical reforms, the most pressing of which we will briefly, but emphatically, mention: Of the greatest importance is the acceleration of the telegraphic service, both for the incoming and outgoing telegrams, and upon an international basis. For this purpose the introduction of a circuit system (as is used in the United States and latterly for other purposes in Germany) appears necessary. It would suffice, if, immediately after the observation, the lines should be placed at the disposal of the Central Institutes for one-half to one hour, during which time they could be placed in possession of the united telegraphic material. This telegraphic matter, including the number of stations and the scope of the data, must of course be reduced as much as possible. With this the introduction of simultaneous (world) time is necessary. The advantages and disadvantages as regards local time would seem to counterbalance one another.

It is greatly to be deplored that in Europe, although it is recognized as a necessity, uniform hours of observation can not be agreed upon. On this point the Institutes should come to a decision.

As soon as the data are collated they should be sent to a number of secondary stations so that within a few hours after the working up of the observations the deduced synopsis and predictions can be given to the public. A suitable remuneration for the trouble of the observers is desirable.

More frequent information, at least three times a day, as is now done at many Institutes, increases greatly the efficiency of the weather service, as well as more frequent issue of predictions when it suits the requirements of the public, for which a principal hour can be easily agreed upon by the Institutions. The idea first suggested by Buys-Ballot to connect the registering apparatus of the chief station continually or occasionally, so that at any time the course of the distant weather elements may be known (tele-meteorology) was nothing more than a dream of the meteorologist which should operate for a short time over a small region. And yet this idea seems very useful for the purposes of weather forecasts, and especially for storm warnings, so that from its moderate cost it is to be recommended for introduction over limited areas, as I have already shown. If the chief telegraphic lines, which at certain hours, especially during the night, are not used, could be arranged for tele-meteorology, the changes of the weather elements at a series of distant stations might be registered continually or intermittently at the principal stations.

The principles which in our region are used for the making of forecasts, I have given in my book on "Weather Predictions," and the opinion expressed is that the fundamental principles are the same

everywhere. In the present state of the science it appears advisable to advance further in the beaten track and thereby to fix and extend the basis.

In weather prediction the distribution of pressure and its manifold changes are of greatest importance, that is to say, the position, the progress, and especially the changes of the high and low pressure areas. The last show, indeed, characteristic weather conditions, but these are greatly modified by secondary formations. These secondaries, which have a much more regular course than is generally supposed, merit chiefly our attention, since their influence on wind and weather is of decided importance. These depressions often make the carefully prepared predictions, especially storm warnings, fail totally. Not infrequently they cause sudden increase of wind, a change in its direction, and consequently great temperature fluctuation and heavy precipitation, and in summer widespread squalls or tornadoes. On the south side of depressions they mostly move quickly over large extents of country; sometimes, moreover, they change their position but little and resolve themselves into an extensive region of low pressure, or fill up. This is the reason why forecasting is associated with so many difficulties which can be the more slowly overcome because the preceding occurrences in the upper air, which, without doubt, have the closest relation to those on the surface, are almost entirely unknown to us.

To what meteorological elements shall the predictions refer? Evidently such as will meet the demands of the public—that is to say (certain conditions excluded), for the coast people, first, wind direction and velocity, then fog, and finally the other elements; for the agriculturists, first, precipitation, next temperature, then cloudiness and wind.

On account of the uncertainty of the predictions, details should be avoided (which are often given) and the doubtful should be more repressed, especially when the weather situation is uncertain, and then the most important elements for practical purposes should be dwelt on. If the weather situation is uncertain this should be stated in the prediction. The intensity of the precipitation is very difficult to predict and can be done only in certain cases. Denmark has to my knowledge the simplest predictions for agricultural purposes which only state whether the weather for the following day will be dry, changeable, or rainy. This method has much value, it seems to me, as at the same time temperature and other predictions are given when they seem necessary to the public and when the weather situation warrants them.

Long experience has shown that the predictions which have the greatest chance of success are those which have the closest relation to the pressure distribution, such as the direction and strength of the

wind; next, those which depend chiefly on the wind and air transportation, that is to say, the temperature phenomena and to some degree the hygrometric conditions of the air. According to this, the prediction of clouds, fog, and precipitation is always more difficult than those of wind and temperature, because here, besides the air movement, other factors occur, such as vertical air currents, topographical conditions, etc. From what has been said it follows that the results of the storm warnings are more favorable than those of the agricultural predictions, although the percentage of success seems to prove the contrary. The reason is that with cloud, fog, precipitation and in less degree with temperature, not only chance but also the persistent tendency play an important role, while the probability of the occurrence of a storm and of its continuance is relatively extremely small, so that even percentages of success which hardly reach 50 ought not to be regarded as unfavorable, though predictions of the severity of the storm and the timeliness of the warnings are of much importance. Evidently predictions which rest only on chance or on persistence are absurd; for it is the changes of weather mainly which must be predicted.

Snowdrifts occur most frequently in certain types of weather, and therefore, the communication of such warnings to the railroads ought to be valuable. Such an arrangement exists in Russia since 1891, and the results have not been unfavorable, seeing that most railroads regard the warnings as useful.

That predictions of the changes of the height of rivers (floods) can well be made has been sufficiently proved by the experience in the United States, in Bohemia, and in other countries.

The value of the predictions, aside from their trustworthiness, is also dependent upon the length of time which they cover. Up to now most of the Institutes issue forecasts only for the following twenty-four hours or for the ensuing civil day. The shortness of this time does not correspond to practical needs; often the prediction only comes to the public on the day for which it applies. A prediction for two, three, or more days in advance, if the accuracy was not very much less than that for one issued one day ahead, would be of the greatest value. It is only a question whether in the present state of practical weather knowledge such a step is desirable. Everywhere experience has shown that in general over large regions the same weather condition lasts a considerable time and then, finally, either slowly or suddenly, is transformed into another more or less opposed; so that, for example, periods of dull, rainy, and stormy weather are followed by clear, dry, and calm weather with which the temperature phenomena, chiefly dependent upon the air movement, on the season, and on the cloudiness, have to do. If a typical weather condition is formed, it appears that a long-range

prediction can safely be made, and it only remains to announce an alteration in the character of the weather or a change of weather. In long-range predictions two cases occur, viz.: (1) To determine the degree of probability that the weather character will last a longer or shorter time, and (2) to predict this change. The last is by far the most difficult, and we ought not to forget that a critical point of weather prophecy lies here—an uncertainty which it must be the aim of practical meteorology to remove, but whose full accomplishment can not be expected at present.

In weather forecasting, the position of the country relative to its system of stations and to the track of low pressure areas is important. The European countries lying to the westward, such as the Iberian Peninsula, France, Great Britain, and Norway, are hardly in a position to issue long-range predictions whose success would be comparable with those issued by the countries lying to the eastward. Towards the south of the globe the changes in general weather character become less, but, on the other hand, local phenomena are more marked. In northern Europe typical weather phenomena are the rule, but the propagation and the changes of the depressions (secondaries) show many changes in which the disturbances coming from northwest and west present the greatest anomalies.

It would be of the greatest advantage for long-range forecasts if the weather service stretched westward into the ocean, both by weather telegrams from the Faroe Islands, Greenland, and the Azores and by telegraphic reports in the eastern regions of the North Atlantic Ocean, from the ports of the trans-Atlantic steamers, which often outstrip in speed the depressions. Thereby would the costly trans-Atlantic telegrams received from Washington, concerning the weather in the west of the North Atlantic, have more value.

The situation of the eastern United States is favorable for weather predictions for some time ahead, although the movement of the maxima and minima is much quicker than in Europe, and consequently the changeableness of the weather is much greater than in Europe, and the more so, since the northern and southern air currents present such extreme contrasts as occur nowhere else over so extensive a region.

In spite of all these ideas, long-range weather predictions can only, according to my mind, be recommended when they are issued with the necessary prudence and when they are made with a strong probability of success. In conjunction with these the customary forecast for the following day should be maintained, as is done at the Weather Bureau at Washington. Recently, the *Seewarte* has given in its weather summary opinions of the probable course of the weather for an indeterminate time, as soon as the weather situation warranted it, and with good results. Latterly, also, in Switzerland long-range

predictions have been made (but not published), and not without success.

The efficiency of the weather prediction can be increased in a high degree by teaching the public the ruling principles and to connect the local observations, made with or without instruments, with the general atmospheric conditions, so that in certain cases it can judge why the actual course of the weather agrees or does not agree with the predicted, and, under certain conditions, how far the forecasts must be modified. Local observations in combination with the general weather situation give results which are not to be undervalued, since in most cases they take into account the changes which the weather conditions undergo in a certain place. In order to enable the public to follow the weather conditions day by day, the circulation of newspaper weather charts appears very desirable, and here I may cite the efforts of the Berlin Weather Bureau, which, increasing year by year, at present furnishes weather maps to seven of the great daily papers, besides those posted on the numerous Urania columns. On the other hand, it is to be desired that the chart issued by the Institute should be sold at a moderate price, or, if possible, distributed gratis. The free distribution of the forecast telegram is also to be recommended.

Unfortunately, we have to admit that such a desirable understanding of practical weather lore is unknown to the public, as well as to learned persons, and we must further admit that the blame rests partly upon the fact that most meteorologists consider it sufficient to present to the public the relatively few principal doctrines of practical meteorology, and do not expose superstitious views or limit their belief. I have already stated the fact that the weather bulletins and charts issued by the meteorological institutes, and partly also the predictions, have only a small practical value if their comprehension be wanting. It is the duty of every meteorologist, so far as he can, to strive in this direction, not only on the ground of utility but also for the advancement of science.

Finally, the accuracy of weather forecasts can be greatly increased if the specific cases be compared with similar previous cases. Therefore it is very desirable to arrange the weather charts of the previous years according to general methods, such as storm tracks, in order that these comparisons may be at once instituted. Thereby our experience and also our skill in making predictions will be greatly advanced; and we are soon able, at the sight of any weather chart, to form a judgment as to the probable sequence of the weather conditions. Such a procedure must be attended with good results, as my own experience has shown. It appears desirable that for vast regions, such as North America and Europe, with the neighboring oceans, a numerous collection of systematically arranged charts should be published which

would permit the course of the elements to be traced from the preceding to the following day. Such an atlas would be of great value, not alone for the Institute but also for the public, which is now often able to form an idea of the prevailing weather conditions from the newspaper weather charts. A special atlas for the agricultural forecasts and one for the storm warnings appears in any case necessary.

Since the Vienna Congress and the Utrecht Conference there has been little accomplished by the meteorological congresses and conferences; therefore it is to be hoped that at the present Congress the most pressing needs will be satisfied.

## APPENDICES.

[Extracts from letters received by Dr. Van Bebber from representatives of weather services in reply to questions relating to the present condition of the weather service in their respective countries.]

### I.—Meteorological Service, Canada.

1. *The degree of accuracy of our forecasts of temperature, rain, and wind for one, two, or three days in advance.*
2. *As to the principles on which the forecasts depend, and the character of the weather we are able to predict.*
3. *As to the advisability of predicting rain; and the extent to which we should predict temperature or other changes viewed from the standpoint of what it is possible to predict with a fair degree of success, and what it is the public cares to know?*

1. The ordinary forecasts of the Canadian Service are issued from the Central Office at Toronto at 11 p. m. daily, and are distributed by the various telegraph companies to nearly every telegraph office in the older provinces, and in Manitoba. The forecast is for the twenty-four hours from 8 a. m. of the morning after issue to 8 a. m. of the following day, *i. e.*, practically a thirty-six-hour prediction; a supplementary forecast is made at 10 a. m. each day, modifying, if necessary, that of the previous night, but is not very generally utilized, as the Toronto and Montreal evening papers and the Toronto Board of Trade are the only means by which the public can obtain them, unless by direct inquiry from Toronto Observatory or the telegraph offices at Toronto.

In making the ordinary forecasts the predicting officer at Toronto endeavors to give the public as accurate an outline as possible of the weather during the prescribed period; he is not bound by any hard and fast rule to predict for every subject that may be included in the general word "weather," such as wind velocity and direction, temperature, rain, and weather in the more restricted meteorological sense, although in every instance he feels bound, even when grave difficulties are to be contended against, to forecast as to the probability

of rain for at least that portion of the prescribed period which lies between 8 a. m. and 11 p. m. of the next day.

As a rule, a prediction is made for wind velocity and direction, weather, temperature, and rainfall, both as regards time and amount for each of the various districts into which the Dominion has been divided. Each morning the forecasts of the previous day are compared with the actual weather, and each item entered in a table under the headings "number of predictions," "number fully verified," "number partly verified," "number not verified." At the end of the month, when more numerous reports have been received, these figures are checked, and if necessary changes made, and a percentage struck by taking half those "partly verified" as verified, and the other half as not verified. In every instance rain is counted as a prediction, absence of rain when predicted being counted a failure, as is also rain when no prediction of it has been made. The tables on pp. 43 and 44 show the degree of success with which we meet in forecasting rain, wind, and temperature, and that, roughly speaking, we are about as likely to fall into error by predicting it too often, as by not predicting it often enough.

It sometimes happens, in the more settled weather, that the predicting officer feels very sure of his ground and makes a two or three day prediction, but no separate percentage of verification of such predictions has been kept. Telegraphic and telephonic inquiries for extended predictions are being continually received at the observatory, and the fact that certain firms, of various descriptions, have for years made a practice of asking for extended forecasts, and by word of mouth and by letter, acknowledged their usefulness, proves that such forecasts are, to say the least, fairly successful.

2. The forecasts as issued from Toronto depend altogether on a knowledge obtained from practice and study of the movements of areas of high and low pressure on this continent, and the weather which, under various circumstances, accompanies these areas, taking fully into account in predicting for certain districts the influence that winds of different directions and increased or diminished moisture will have in the various cases. The predicting officer has by experience learned much as to the influence that areas of high pressure and of low pressure will probably have on each other as regards development or dispersion and rate of movement, and makes his predictions on the basis that the pressure changes will be as he anticipates. It is not an uncommon thing for him, when an abnormal movement of a cyclone has occurred, to base a prediction on the assumption that such movement was either directly or indirectly caused by another cyclone beyond the region of observation, for instance at sea, and in this manner many storms on our seaboard have been foreseen, the existence of which would otherwise not have been suspected.

Although, up to the present time, very little use has been made of the kind and direction of upper clouds, it is full well recognized that a greater knowledge of the relationship of the upper currents to cyclones and anti-cyclones may ultimately lead to more exact and extended forecasts. Even at present weather prognostics dependent on clouds are not by any means ignored, as in cases of doubt as to the hovering or change in direction of movement of a cyclone, such indications are at times of decided value.

3. What is it the public cares to know? The mariner wants to know, just prior to sailing, the force and direction of wind he may expect during periods varying from a few hours to several days; fishermen are ordinarily satisfied with twenty-four-hour forecasts; the agriculturist wants to know generally as to the likelihood of rain during harvest time, and, in the case of the Northwest farmer, the likelihood of early frosts; the shipper of perishable goods wants to know the best time to ship in order to escape severe frost; the general public wants to know the general character of the weather to be expected on any given day and the day following.

Our ordinary forecast percentages show that we are able to predict direction and velocity of wind with tolerable accuracy for a period of thirty-six hours, and, at times, for a longer period, and we have a percentage of verification of storm warnings of 84 per cent; therefore, the meteorological service is of benefit to the mariner.

Our percentages show a verification of 74 per cent for thirty-six-hour forecasts of rain. We know that the public generally, and the agriculturist in particular, consult the probabilities and believe in them; therefore, it is obviously advisable to predict rain.

Our percentages show a verification of 84 per cent for temperature for thirty-six-hour forecasts, and during winter the service is continually consulted as to cold waves, etc. This shows that temperature predictions are possible, and are appreciated by that portion of the public more directly interested.—*R. F. Stupart, Predicting Officer.*

*Table showing percentage of verification of predictions of rain, temperature, and wind velocity.*

| Predictions.* | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PRECIPITATION. | | | | | | | | | | | | | |
| 1890— | | | | | | | | | | | | | |
| Number | 152 | 120 | 130 | 128 | 131 | 125 | 153 | 131 | 137 | 136 | 122 | 142 | 1,607 |
| Fully verified | 108 | 92 | 83 | 79 | 81 | 78 | 108 | 94 | 103 | 82 | 69 | 104 | 1,081 |
| Partly verified | 32 | 12 | 20 | 17 | 25 | 18 | 20 | 16 | 15 | 25 | 27 | 17 | 244 |
| 1891— | | | | | | | | | | | | | |
| Number | 133 | 115 | 132 | 153 | 147 | 161 | 159 | 156 | 160 | 151 | 152 | 159 | 1,778 |
| Fully verified | 78 | 73 | 79 | 90 | 95 | 110 | 113 | 93 | 104 | 105 | 112 | 102 | 1,154 |
| Partly verified | 26 | 16 | 30 | 30 | 20 | 26 | 24 | 32 | 14 | 20 | 17 | 28 | 283 |
| 1892— | | | | | | | | | | | | | |
| Number | 153 | 148 | 164 | 154 | 152 | 155 | 181 | 155 | 155 | 155 | 155 | 166 | 1,893 |
| Fully verified | 86 | 98 | 105 | 119 | 98 | 96 | 128 | 94 | 100 | 98 | 92 | 110 | 1,224 |
| Partly verified | 47 | 31 | 26 | 24 | 33 | 30 | 30 | 24 | 23 | 28 | 32 | 32 | 360 |

*Table showing percentage of verification, etc.*—Continued.

| Predictions. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Precipitation**—*Continued.* | | | | | | | | | | | | | |
| Total for three years— | | | | | | | | | | | | | |
| Number | 438 | 383 | 426 | 435 | 430 | 441 | 493 | 442 | 452 | 442 | 429 | 467 | 5,278 |
| Fully verified | 272 | 263 | 267 | 288 | 274 | 284 | 349 | 281 | 307 | 285 | 273 | 316 | 3,459 |
| Partly verified | 105 | 59 | 76 | 71 | 78 | 74 | 74 | 72 | 52 | 73 | 76 | 77 | 887 |
| Total percentage for three years | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | ... | .... | 73.9 |
| **Temperature.** | | | | | | | | | | | | | |
| 1890— | | | | | | | | | | | | | |
| Number | 156 | 113 | 121 | 122 | 119 | 108 | 117 | 110 | 129 | 101 | 105 | 149 | 1,450 |
| Fully verified | 123 | 89 | 92 | 101 | 85 | 71 | 108 | 97 | 124 | 86 | 90 | 120 | 1,186 |
| Partly verified | 18 | 4 | 15 | 11 | 18 | 12 | 8 | 11 | 4 | 11 | 8 | 13 | 133 |
| 1891— | | | | | | | | | | | | | |
| Number | 141 | 94 | 145 | 147 | 141 | 146 | 153 | 141 | 149 | 136 | 146 | 163 | 1,702 |
| Fully verified | 90 | 73 | 124 | 108 | 101 | 123 | 126 | 120 | 118 | 115 | 124 | 132 | 1,354 |
| Partly verified | 26 | 11 | 14 | 21 | 32 | 18 | 17 | 17 | 15 | 12 | 13 | 20 | 216 |
| 1892— | | | | | | | | | | | | | |
| Number | 148 | 142 | 151 | 142 | 128 | 138 | 168 | 151 | 157 | 141 | 123 | 148 | 1,737 |
| Fully verified | 104 | 100 | 110 | 120 | 102 | 101 | 139 | 118 | 120 | 116 | 101 | 116 | 1,347 |
| Partly verified | 23 | 31 | 18 | 14 | 19 | 27 | 15 | 16 | 22 | 14 | 8 | 15 | 222 |
| Total for three years— | | | | | | | | | | | | | |
| Number | 445 | 349 | 417 | 411 | 388 | 392 | 438 | 402 | 435 | 378 | 374 | 460 | 4,889 |
| Fully verified | 317 | 262 | 326 | 329 | 288 | 295 | 378 | 335 | 362 | 317 | 315 | 368 | 3,887 |
| Partly verified | 67 | 46 | 47 | 46 | 69 | 57 | 40 | 44 | 41 | 37 | 29 | 48 | 571 |
| Total percentage for three years | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | 83.7 |
| **Wind velocity.** | | | | | | | | | | | | | |
| 1890— | | | | | | | | | | | | | |
| Number | 58 | 50 | 98 | 80 | 89 | 81 | 126 | 75 | 45 | 64 | 84 | 95 | 945 |
| Fully verified | 35 | 33 | 70 | 48 | 59 | 67 | 107 | 57 | 36 | 45 | 57 | 68 | 682 |
| Partly verified | 15 | 2 | 18 | 19 | 21 | 10 | 12 | 11 | 7 | 10 | 19 | 10 | 154 |
| 1891— | | | | | | | | | | | | | |
| Number | 39 | 70 | 84 | 87 | 99 | 114 | 50 | 38 | 107 | 93 | 94 | 82 | 957 |
| Fully verified | 26 | 59 | 57 | 59 | 86 | 88 | 43 | 27 | 77 | 62 | 68 | 46 | 698 |
| Partly verified | 4 | 8 | 12 | 24 | 11 | 16 | 2 | 8 | 16 | 14 | 17 | 10 | 142 |
| 1892— | | | | | | | | | | | | | |
| Number | 81 | 46 | 60 | 62 | 68 | 57 | 101 | 53 | 80 | 85 | 90 | 36 | 819 |
| Fully verified | 50 | 28 | 31 | 45 | 48 | 40 | 78 | 29 | 46 | 51 | 64 | 23 | 533 |
| Partly verified | 18 | 8 | 12 | 10 | 14 | 12 | 17 | 16 | 18 | 14 | 14 | 4 | 157 |
| Total for three years— | | | | | | | | | | | | | |
| Number | 178 | 166 | 242 | 229 | 256 | 252 | 277 | 166 | 232 | 242 | 268 | 213 | 2,721 |
| Fully verified | 111 | 120 | 158 | 152 | 193 | 195 | 228 | 113 | 159 | 158 | 189 | 137 | 1,913 |
| Partly verified | 37 | 18 | 42 | 53 | 46 | 38 | 31 | 35 | 41 | 38 | 50 | 24 | 453 |
| Total percentage for three years | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | 78.6 |

*Rain predictions for June.*

| Year. | Number of predictions. | Fully verified. | Partly verified. | Not verified. | Percentage fully verified. | Percentage fully and partly verified. |
|---|---|---|---|---|---|---|
| 1888 | 11 | 9 | 1 | 1 | 81.8 | 91.0 |
| 1889 | 12 | 7 | 3 | 2 | 58.3 | 83.3 |
| 1890 | 14 | 9 | 3 | 2 | 64.3 | 85.7 |
| 1891 | 15 | 9 | 3 | 3 | 60.0 | 80.0 |
| 1892 | 13 | 9 | 3 | 1 | 69.2 | 92.3 |
| | 65 | 43 | 13 | 9 | 66.2 | 86.2 |

*Days of no rain predictions.*

| Year. | Number of days. | Fully verified. | Partly verified. | Not verified. | Percentage fully verified. | Percentage fully and partly verified. |
|---|---|---|---|---|---|---|
| 1888 | 15 | 12 | 2 | 1 | 80.0 | 93.3 |
| 1889 | 13 | 6 | 3 | 4 | 46.2 | 69.2 |
| 1890 | 11 | 8 | 2 | 1 | 72.7 | 91.0 |
| 1891 | 11 | 9 | 1 | 1 | 81.8 | 91.0 |
| 1892 | 13 | 6 | 3 | 4 | 46.2 | 69.2 |
| | 63 | 41 | 11 | 11 | 65.1 | 82.5 |

## II.—Danish Meteorological Institute.

### COPENHAGEN.

We issue only storm warnings. For nautical purposes, signals are displayed in Helsingör for the wind conditions in the Cattegat, which signals can be seen by ships about to sail. The daily weather review is also posted in each port.

Our daily weather map is based on the morning telegrams from three English, three Norwegian, seven German, four Swedish, two Russian, nine French, and eleven Danish stations. Every day a summary of the weather situation is given, as well as the weather forecast. The forecast is only expressed in general terms, and we take no pains to name each element in our forecast. Hektographic copies are posted in various parts of the city as well as at the port. The review and forecast are telegraphed at 2 p. m. to all telegraphic stations and then publicly displayed. During the months of June to September an afternoon service is maintained. The review and forecast are based on meteorological dispatches from three English, one Norwegian, two German, one Swedish, and four Danish stations. The forecast relates mainly to precipitation, and the following terms are used: "clear weather;" "generally clear weather;" "changeable weather," and "rainy weather." The forecast is telegraphed at 5 p. m. to all the telegraph stations. At many places the forecast is transmitted from the nearest telegraph office to the neighborhood by optical signals.—*Adam Paulsen, Director.*

## III.—Norwegian Meteorological Institute.

### CHRISTIANIA.

We receive telegrams from Norway, Sweden, Denmark, the British Islands, France, North Germany, and Russia. Besides synoptic charts of the preceding evening and the morning, we construct charts of change of pressure from evening to morning, change of temperature in the last twenty-four hours (8 a. m.), deviation of the temperature at 8 a. m. from the normal, and temperature distribution at 8 a. m. Only the synoptic charts are posted. For the greater part of the year our predictions (extending from noon to noon) are only published in Christiania. In all months they apply only for Christiania and neighborhood. The area is more limited in winter than in summer. In winter we predict, as far as we can, temperature, precipitation, and wind. In the summer months (June–September) the predictions, intended for farmers, give precipitation. These are telegraphed and telephoned southward to Skien, northward to Hamar, westward to Randsfjord, eastward to the boundary of the kingdom. We have attained 90 to 92 per cent of success.

Storm warnings are only occasionally sent to the coast when the

weather signs in Scotland at 8 a. m. have begun to give warning. Storm warnings are not sent farther north than Bodö. The shore community is satisfied. We have received latterly pecuniary aid from the Storthing in order to undertake special weather studies with the intention of establishing local systems of weather warnings with local centers in Bergen, Throndheim, and at the great fisheries (Lofoten, for example) under the direction of local meteorologists as directors. The principles according to which we issue warnings are hard to analyze—scientific instruction, local experience, imagination. It is quite as much an *art* as a science which one practices.—*Dr. H. Mohn, Director.*

## IV.—Russia: Central Physical Observatory.

### SAINT PETERSBURG.

I send you reports of the observatory for the years 1886–1891, as well as the report concerning the service of the forecasts of snow-drifts on the railroads. With the permission of the director, Dr. H. Wild, I add an extract from the report for 1892. The rules which we follow for weather predictions are about the same as stated in your (Dr. Van Bebber's) excellent book, which is used as a text book in the forecast department.

Since July, 1892, after previous trials, the general weather predictions have been subjected to regular tests, as published in the bulletin. The predictions for the districts of European Russia (compare map in supplement to Daily Bulletin) have been separated and verified for the four elements of precipitation, cloudiness, temperature, and wind. For each of the elements three grades were distinguished, a high, a mean, and a fair grade. The predictions were considered as successful when, at the majority of stations in the given district, the predicted phenomena were observed in the predicted degree. As partly successful were taken those predictions for which the phenomena did not show the indicated grade but the next one to it. As unsuccessful predictions were regarded those for which the opposite of the predictions was observed.

*Example.*

| Prediction. | Observation. | Verification. |
|---|---|---|
| Thick clouds | Thick clouds | Successful. |
| | Cloudy | Partly successful. |
| | Fair | Failure. |

In the final verification of the degree of success of the prediction the number of partly verified predictions is distributed, half to the successful and half to the unsuccessful prediction.

The exact determination of the notation, the sub-division of the districts, and the choice of the grade for the characteristic weather demand, however, special meteorological researches; consequently, the verification adopted for 1892 is to be regarded as a first attempt to determine the proper criteria.

The results of the verification are given in percentages in the following table:

*Verification of the general weather predictions for six months (July–December) of* 1892.

| | Predictions. | |
|---|---|---|
| | Successful. | Unsuccessful. |
| | *Per cent.* | *Per cent.* |
| DISTRICTS: | | |
| Northwestern Russia | 80.6 | 19.4 |
| Western Russia | 77.2 | 22.8 |
| Central Russia | 82.5 | 17.5 |
| Northeastern Russia | 80.8 | 19.2 |
| Eastern Russia | 85.6 | 14.4 |
| Southeastern Russia | 79.0 | 21.0 |
| Southwestern Russia | 80.9 | 19.1 |
| ELEMENTS: | | |
| Precipitation | 75.8 | 24.2 |
| Cloudiness | 85.6 | 14.4 |
| Temperature | 80.2 | 19.8 |
| Wind | 79.5 | 20.5 |
| Mean | 81.0 | 19.0 |

Besides the general weather predictions which are published daily in the bulletin, more than one hundred and fifty replies are given by the department to private inquiries (mostly from Perm and Nizhnee-Novgorod) concerning the expected weather. Besides this, during three months (in summer and autumn) daily weather predictions are made for Pawlowsk.

From the preceding table it is evident that the percentages of the successful predictions for the different districts of European Russia are dissimilar, being larger in the east and smaller in the west. This difference is more marked in the comparison of the results of predictions for single places. The number of successful predictions for those stations lying in the east (Perm, Nizhnee-Novgorod, Saratov, etc.) is 80 to 81 per cent, while in Pawlowsk it only reaches 63 to 64 per cent.

In the supplement we reproduce three letters[1] from Mr. Panaew and one from Mr. Batjuschkow, in which the writers express their thanks for the predictions sent them. From these letters it appears that our predictions are practically useful; this result is for us the more satisfactory since it is not based on single chance forecasts, but upon a whole systematic series of predictions, of which naturally a certain percentage may be bad. It should here be remarked that both the above-mentioned gentlemen were subscribers to the telegraphic

[1] These letters were not received by me.—EDITOR.

weather predictions and in consequence paid for each one a tax of 50 kopecks besides the usual tax. In both letters the wish is expressed that further progress may be made.

*Storm warnings for the Baltic and for the Black and Azof Seas in* 1892.

[The general results, expressed in percentages, are for all districts.]

| Warnings. | Baltic. | Black. |
|---|---|---|
| Verified | 63 | 65 |
| Partly verified | 22 | 11 |
| Late | 5 | 12 |
| Not verified | 10 | 12 |

The percentage of storms which were not predicted, whose force exceeded that indicated by one ball, was, for the Baltic Sea, 10 per cent (1891, 13 per cent); for the Black Sea, 19 per cent (1891, 23 per cent). If we combine the verified and partly verified warnings the result of the successful warnings for 1892 is as follows: Baltic Sea, 85 per cent (1891, 76 per cent); Black Sea, 76 per cent (1891, 69 per cent).—*Ch. Rykatchew.*

## V.—The Weather Service in Austria.

### VIENNA.

In Austria the issue of a telegraphic weather report was begun January 1, 1877. This service is carried on by three officials of the "Section for Weather Telegraphy," whose office since the year 1879 is in the center of the city in the building of the Imperial Academy of Science. The telegraphic material has increased notably since 1877. At present there are received daily weather reports from thirty-six Austro-Hungarian and from sixty-six foreign stations. These are dispatched in twelve combination telegrams to 158 domestic and foreign stations. The monthly subscription price for the weather report is 1 fl., 50 kr. The weather report goes to the printer not later than 3 o'clock, and is sent out regularly before 5 o'clock. At the present time there are ninety-nine subscribers to the weather report; the number of free, exchange, and obligatory copies amounts to eighty. Besides the printed weather report, there have been sent since 1877 daily prediction telegrams which go chiefly to the landed proprietors, health resorts, and the larger provincial papers. Since the year 1884 the prediction telegrams have been in cipher, whereby the subscription price has been reduced 50 per cent to its present price of 5 fl. per month. The telegrams are issued generally between 1 and 1.30 p. m.

The success of the predictions is, on the whole, satisfactory, averaging 85 per cent. The subscribers to the prediction telegrams have varied since 1878 from fifty to eighty-three. As regards the relation of the public and their interest in the weather to the prediction service, the journalists hold an important place. In Vienna all

the great newspapers are forced by their readers and correspondents, both in the morning and evening editions, to print the telegraphic weather reports with the predictions. When, from lack of space or other reasons, the weather report does not appear, complaints come at once to the publishers. The confidence in the weather predictions manifests itself most strongly in the fact that not only the Viennese, but also the great proprietors in the provinces take pains to procure the predictions.—*Dr. J. Hann, Director Central Bureau for Meteorology and Terrestrial Magnetism.*

### VI.—Hungarian Meteorological and Magnetic Bureau, Budapest.

Weather predictions were issued in 1881 by direction of the Minister of Agriculture, at that time Baron Kemsny, by Dr. Szentgyörgyi Weisz, who, however, was independent of the Meteorological Institute. The dissemination of the forecasts was accomplished through the newspapers; the telegraphic dispatches were insufficient and after eight years' continuance this arrangement was given up.

In the year 1888 the task of making weather predictions was entrusted to the Meteorological Institute, but still, this service, in the too narrow limits to which it was confined by the previous organization, could get no firm hold.

A noteworthy advance in this field can be recorded when I took the direction of the Central Bureau. On June 15, 1891, our first synoptic charts appeared, whose issue was facilitated by a subvention from the Minister of Agriculture. The forecasts were publicly posted in Budapest and their circulation was confined to the daily newspapers. On account of the great importance of the predictions in an agricultural state like Hungary, a quicker and more general dissemination of the forecasts was desirable. The present Minister of Agriculture, Count Andreas Bethlen, manifests a lively interest in the matter and, acting on my suggestion, has succeeded in enlisting the Ministry of Commerce. The creation of such a method of forecast dissemination as exists in Hungary, according to my knowledge, has not come about in any other European country.

There was inaugurated, primarily, a general official method of distributing the predictions in the interest of the farming community. Accordingly, on August 1, 1892, the first forecast dispatch (in cipher) was issued as an appendix to the official "circular dispatch," which contains the quotations of the Budapest merchandise and grain exchanges, and by way of experiment this forecast dispatch was sent to one hundred and thirty telegraph offices for official distribution to the public. Each of these telegraph operators received, also, a suitable bulletin board on which the data and the announcements forming the forecasts were to be hung. There belong with each board

twelve small tablets for the different months, thirty-one tablets (bearing the numbers 1–31) for the days, and thirty-one for the predictions. On the last are, together with the cipher, also the announcements belonging to each. The telegraph operator is thus relieved of all trouble of translation; his task consists only in taking from a box that tablet which bears the cipher of the forecast dispatch just received and in hanging it up.

This method of spreading the information deserves to be mentioned because it is a free one and is solely for the benefit of the agricultural community. Much public interest is everywhere manifested, and the agricultural societies in many counties have applied to the Government for an increase in the number of telegraph operators who have been entrusted with the receipt and the publication of the forecast dispatches, so that at present one hundred and thirty officials have been appointed, and after May 1, 1893, two hundred and sixty telegraph offices will serve to disseminate the predictions. Further, for remote places and for Puszten (inns in out-of-the-way localities) an optical method of signaling is projected, so that by displaying different colored flags, baskets, and cones (made of osier) the forecasts will be made known. On my estate in O'Gyalla and on that of the Minister in Bethlen this scheme is already in operation.

The forecasts relate, exclusively, to the conditions which are of interest to farmers, that is to say, especially to precipitation and temperature and, incidentally, to cloudiness. Storm warnings are not issued. The forecasts apply for the following twenty-four hours, but in consequence of the importance which a forecast of the weather for two days ahead possesses for agriculture, in certain cases of weather stability one is undertaken for two days with the announcement, "weather conditions persistent (w)," as well as, when the weather condition admits, a change for the second day is indicated by "later precipitation (x)," or "later clearing (z)." The variability of the climatic conditions requires that from the extent of Hungary, in special cases, the rain probability should only relate to certain regions, which is indicated by the announcements "precipitation in the west (l)," "precipitation in the south (j)," etc. The forecast dispatches are sent until 3 o'clock each afternoon from the Institute to the telegraphic centers.

At present the Meteorological Institute is hoping for a reorganization which will create a special section for "Weather Telegraphy and Forecasts." It will only then be possible to study the weather conditions in detail from the point of view of forecasts, and to prepare the needed statistical data.

Regarding the success of the forecast dispatches, I can only now cite the computed results which relate to the quarter August-October, 1892. The figures are obtained by a comparison of the forecasts

with the records, at the hours 7, 2, and 9, of twelve uniformly-distributed meteorological observing stations. These forecasts were verified in the above-mentioned quarter, for precipitation, 84.7; temperature, 76.1; and cloudiness, 86.2 per cent. With the establishment of a special section it is the intention to develop further the whole forecasting service, of which I may speak more at length later.—*Dr. N. von Konkoly, Director.*

## VII.—The Weather Service in the Netherlands.

### UTRECHT.

*Installation.*—At Utrecht, after the arrival of the dispatches from the Netherlands, about 10 to 11 a. m., the report is placarded and published in the morning edition of the local newspapers which appear about 1 p. m. Beneath the report is entered the greatest barometric deviation which is (graphically) represented on the aëroklinoskop (*cf.*, *Invoering en Verklaring*, translated by Dr. Jelínek with the title *The Aëroklinoskop*). In the afternoon, about 3 p. m., the weather chart, manifolded by the hektograph process, is issued, beneath which is a summary of the greatest barometric deviation at 8 a. m. and 12.30 p. m., and a weather prediction for the twenty-four hours following the observation. The weather charts published at Utrecht are sent elsewhere on payment of postage.

*Results.*—The results of the predictions are seldom expressed by figures. Results of the storm warnings, which are based on the differences of the barometric deviations, are published annually in the *Niederländischen Meteorologischen Annalen.* The results of the two last years are that 60 per cent of the storm warnings were not verified.

*Presentation to the public.*—The organization of the weather service, which is essentially represented by the *Telegraphisch Weerbericht ten dienste van den Landbouw* and which dates from the close of 1882, was for several years unfavorably regarded by the public, just as the storm warnings were for the fifteen or twenty years preceding. There followed a period, which still continues, when the public, took little or no notice of the weather reports. Only about 1889 was there shown a greater interest by the public which manifested itself in the appearance of a daily weather chart in two newspapers, the first and up to now the only ones in the Netherlands to publish these charts.

*The degree of accuracy in predictions of temperature, snow, rain, or wind, two or three days in advance. What principles are adopted in such predictions?* Utrecht issues a definite wind prediction, which is founded on the difference of the barometric deviation, and a more or less detailed weather prediction for the ensuing twenty-four hours. A temperature and wind prediction is seldom made for the second twenty-four hours, never for the third, and never, as regards rain, for the second period. These predictions, like those for the first twenty-

four hours, are based on the determination of the current gradient (not barometric gradient) of the air in a vertical and horizontal direction, on the modifications which they may undergo during the day, and on the physical changes which may result.

It is desired chiefly to predict those weather elements which are most related to the duration of the prediction, such as temperature and rain, for example.

Rain prediction is the most important for the public, and is also the most uncertain; even the thunderstorm prediction, which has even more value and also is the surest, has often only a local verification.—*Abridged translation by Mr. Engelenburg.*

### AMSTERDAM.

The weather service in Amsterdam furnishes information about the weather not only to the public in Amsterdam, but also to the *Staatsanzeiger* and the *Harlemmer Zeitung.* These papers receive as full a summary as those in Amsterdam. The report is telegraphed to the *Staatsanzeiger* each noon, while the *Harlemmer Zeitung* sends for it. The latter paper wishes no tabular data, but only a summary. Besides, there is sent to other places in the Netherlands a weather summary, with a wind prediction added to the *Telegraphisch Weerbericht ten dienste van den Landbouw.* These reports are published by harbor-masters, provincial newspapers, etc. Finally, in many places in Amsterdam, and also in Harlem and at the office of the *Harlemmer Zeitung,* hektographic weather reports are posted.

I believe the value of the *Telegraphisch Weerbericht ten dienste van den Landbouw* to be very small. A mere statement that "a depression lies northwest and far off" or "a high pressure area northeast and in the neighborhood" is incomprehensible and of no value to the public.

The abstracted tables containing data for some domestic and foreign stations may, however, be useful, but, in general, I do not think that the ordinary newspaper readers care much for the report. It is otherwise with seaports, where great differences in the barometric deviations may serve as warnings to seamen. This branch of the service should, according to my ideas, be better supported. The aëroklinoskop, which is set up in some places, does not fulfill the want. To the ports (especially Delfzyl, Nieuwe-Diep, Ymuiden, Zandvoort, Scheveningen, Maassluis, Vlaardingen, Hellevoetsluis, Brouwershaven, Vlissingen) storm signals, analogous to those of the *Deutsche Seewarte* or those long employed on the English coast, should be supplied. The aëroklinoskop can only be read at a little distance, and demands too much imagination on the part of the simple fishermen and seamen.

The reports which the *Amsterdamer Zeitung*, the *Harlemmer Zeitung*,

and the *Staatsanzeiger* receive are fully appreciated by a portion of the public, really more than the editors of the papers realize. The *Harlemmer Zeitung* shows that the public does not know exactly for how long the prediction applies, since a great part of its readers believes that the whole of the next day is included in the prediction. In Amsterdam the prediction never extends more than twenty-four hours, and since the report is made up between 12 and 2 (including the last observation at 12.30 p. m., from the interior) the prediction extends from noon of one day to noon of the next. According to my ideas, it is too uncertain to make predictions for two or three times twenty-four hours, for in such cases the disappointment is greater and the confidence is decreased. For inland places where the papers, unlike the *Staatsanzeiger*, do not receive a full report, and give it only in the evening to their readers (until the *Telegraphisch Weerbericht ten dienste van den Landbouw* makes way for a better arrangement), the weather reports, consequently, can be of little use.

The predictions, as they are now carried on in Amsterdam, indicate: Wind direction, and in the case of great barometric differences, wind force; also the general weather, designated as follows, "good weather," "tolerably good weather," "little change," "changeable weather," "squally weather," "boisterous weather," etc. When the condition of the depression is accompanied by a strong tendency to rain there is added to the prediction "much probability of rain," "rain or snow," etc. Finally, there is sometimes hazarded, as regards temperature, something in the nature of a conjecture—"warm weather," "cold weather," "higher temperature," "lower temperature." Since the rain and temperature predictions can be made with much less certainty than those for wind and general weather, they are not usually given and only when their fulfillment is tolerably certain.

Agriculture should derive the greatest advantage from these rain and temperature predictions, and therefore it is my opinion that agriculture receives no material advantage from the weather service. Navigation, on the contrary, which is chiefly concerned with wind and general weather, can derive much benefit from the weather service, especially when storm signals can be given the ports. I would mention that in Ymuiden there are often sent to war and sometimes to merchant vessels, ready to leave, a complete dispatch containing a rereview and a forecast. Further, according to my idea, by the employment of a private telephone line the harbor and fishing port of Ymuiden could receive much better information than it does now. Probably Maassluis, opposite Rotterdam, is in the same situation.

The wind and weather predictions, as drawn up in Amsterdam, are based on the general situation in Europe at 8 a. m., and on the probable changes and their sequences, for which the *Handbuch der aus-*

*übenden Witterungskunde* of Dr. W. J. Van Bebber, and more recently the *Wettervorhersage* of the same author, are used as guides.

If one considers that in the Netherlands only once in twenty-four hours a review of the situation over Europe can be had, and in Germany, for example, this is made three times a day, it appears to me that the result of the predictions in Amsterdam is not wholly unfavorable. It is very much to be desired, that (for example at 1 p. m.) some dispatches should be received directly from England, France, and Germany (for example six or eight) and immediately charted. If that could be done, the value of the prediction would thereby be greatly increased. Nevertheless, I repeat, no dispatch should be more than one hour late.

In brief, my opinion is, that apart from some progress which may still be made in meteorology as a science, it is very desirable, as may now be done, by an acceleration of the dispatches and a proper means of distributing and publishing the reports, that the public should derive greater advantage from the reports than is at present the case.—*Abridged translation by L. Roosenburg.*

### ROTTERDAM.

The weather service in Rotterdam is confined to the communication of weather reports to the papers published in Rotterdam and the distribution of this report within the parish. This is accomplished by mere mechanical working up of the dispatches received; it seems to me, therefore, that a central bureau can hardly be spoken of. Predictions are not made here, unless the paragraph which follows the barometric deviations from the normal be regarded as such, for example, the paragraph "indicates a .... wind," or in the hektographic weather reports "according to the Buys-Ballot law, there should be a .... wind."

I have left these expressions because it is difficult to give a full explanation each day, but I do not consider them as forecasts. It is only the statement of two phenomena between which there exists a certain relation without our being able to say in general that one is the cause and the other the consequence.

The value of weather predictions published for the public appears to me doubtful, especially because to the forecasts which are unsuccessful much more attention is paid than to the others.

From private telegrams, especially in commercial circles, it has often been shown to me that much interest attaches to weather reports which make known the true situation, and that it is to be regretted that our reports do not cover a larger portion of Europe.

The method of procedure here is as follows: At noon, the *Scheepvoort* newspaper sends for a list of the reports already received. This list is posted outside a window of the newspaper office in the neighbor-

hood of the Exchange. At certain seasons, dependent on the sugar crop, a copy of this is posted in the Exchange. Between 2 and 3 o'clock a complete weather chart is hektographed, and the *Scheepvoort* distributes sixteen copies throughout the city, which are accessible to the public at large, and are also posted in localities where many interested persons assemble, as for example, exchanges, commercial clubs, societies, etc., for the benefit of navigation, navigation schools, trades unions, etc. Further, about 6 p. m., there appears in the *Scheepvoort* a small map, printed by the Rung system, and about 5 o'clock a full list with a general review is published in the *Neue Rotterdamer Zeitung*. This paper, also, has received for some time past a graphic representation, in a form devised by the editors, of the highest and lowest barometer and the temperature during the five preceding days.

The great expense which the *Scheepvoort* incurs, as well as the large space which the *Neue Rotterdamer Zeitung*, from interested motives, devotes to this matter, and the questions which occasionally reach me through the editors of these papers, impress me with the fact that they count among their readers many who are interested in this subject.—*Abridged translation by Arkenbout Schokker.*

## VIII.—London Meteorological Office.

Dr. Van Bebber's letter asks various questions: (1) As to the degree of accuracy in our forecasts of temperature, rainfall, wind, etc., for one, two, or three days in advance. (2) As to the principles on which the forecasts depend, and the character of the weather we are able to predict. (3) As to the advisability of predicting rain, and the extent to which we should predict temperature or other changes viewed from the standpoint of "what it is possible to predict with a fair degree of success and what it is that the public cares to know."

The following replies are drawn up, not exactly in the order in which the queries are put, but in such an order as enables me to reply more clearly and briefly than I could otherwise do.

"Forecasts" or "predictions" are issued by this office, as follows:

The first are prepared at 10.30 a. m., and issued at 11 a. m. (Sundays, Good Fridays, and Christmas days excepted), and are mainly dependent on the observations taken at 8 a. m. daily (see copy of the Daily Weather Report) and relate to the weather to be expected during the twenty-four hours ending at noon on the following day. They are intended chiefly for publication in the Daily Weather Report, in the afternoon newspapers, and for exhibition at certain positions in the city and west end of London, including most of the clubs.

The second are prepared at 3.30 p. m. (Sundays, Good Fridays, and Christmas days excepted) from 2 p. m. observations, and made at a limited number of stations, as supplementary to the 8 a. m. ob-

servations. They relate to the weather of the ensuing civil day. They are always posted at the door of the office for inspection by the public and during the hay and wheat harvests are telegraphed gratuitously to a selected number (about twenty-eight) of agriculturists who make their contents known as widely as possible, and keep a careful check on their accuracy.

The third are prepared at 7.30 p. m., daily, and are issued at 8.30 p. m. These also relate to the weather of the ensuing day, and are dependent on observations made at 6 p. m., as supplementary to those made at 8 a. m. and 2 p. m. They are intended mainly for publication in the morning newspapers of the following day.

They are, therefore, all of them, for a period of rather more than twenty-four hours in advance of the time of issue, and are utilized in answering inquiries by the public as to coming weather.

Special "warnings" as to the advance of storms are sent by telegraph to the coasts threatened, whenever the indications are believed to be of a stormy character. These may be sent at any hour between 9.30 a. m. and 8 p. m., and are made known by the hoisting of a cone (point up for northerly, point down for southerly gales) at the ports to which they are sent.

In the forecasts the wind (direction and force) and the weather are predicted separately, in a somewhat general manner, as the districts for which they are prepared cover a considerable area. In the weather portion any kind of weather is included, if it is likely to be a prominent feature, but at present hardly any attempt has been made to estimate the intensity of coming rain—the local variations in the character of the country and the variations in intensity of thundershowers being too abrupt to make minute detail desirable. Such expressions, however, as "rain at times—heavy locally" are employed when deemed necessary.

With regard to changes of temperature, two distinct classes are kept in view, (1) those of a general and (relatively) of a permanent character affecting the mean temperature of the approaching period, and referred to in such expressions as "colder," "much colder," "warmer," "much warmer," etc., and (2) those of a diurnal character which, in such periods as that recently experienced over our islands, are very large, and are referred to in sentences such as "cold at night, warm during day." No attempt has been made hitherto to check the accuracy of such forecasts, except as forming part of the weather portion of the predictions, but it is believed that they are as good as those for any of the other features included in the forecasts.

With regard to the success which has attended the issue of the forecasts, reference may be made to many distinct sources: (1) to the official checking of the 8.30 p. m. issue, carried on in this office from the information received daily by wire. The results of this

checking will be found on pp. 11 and 63 of the Report of the Meteorological Council for year ending March, 1892, and are very fairly satisfactory. (2) To a similar checking of the 3.30 p. m. forecasts, based on information supplied by the recipients of the forecasts (see same report pp. 12–13) and the favorable opinion expressed by them in their letters to the council; also, to the fact that the same gentlemen are glad, year after year, to receive the forecasts, to make them known, and to keep the record necessary to check them. (3) That among those who make inquiry privately, the same names appear regularly in successive years, whenever the information is required, although a fee is levied for it, and the costs of transmission by wire (when necessary) are paid by the applicant. (4) To the facts that (*a*) the National Lifeboat Institution applied recently to have the forecasts telegraphed daily to the officers in charge at their various stations, as a guide to them in their duties (a request which was reluctantly declined only because the cost of nearly £1,000 per annum was more than the Meteorological Council were able to meet), and (*b*) that the Agricultural Department is even now endeavoring to make arrangements for telegraphing the 3.30 p. m. forecasts daily to all agricultural districts during harvest time. (5) That the authorities at Her Majesty's Dockyard, Devonport, now have the 11 a. m. forecast telegraphed to them every day for guidance in sending the smaller vessels to sea; and that Her Majesty never puts to sea without having the latest forecast transmitted to her by wire. (6) That the newspapers in all parts of the kingdom have not only published the forecasts regularly for many years, but in most cases pay a considerable sum for cost of telegraphy, when the offices are too far distant for them to be delivered by hand, and that *The Times* paid £500 per annum for the exclusive use of the 6 p. m. forecasts, and subsequently the three leading London papers paid £900 per annum between them for the use of the same forecast until the Government made a grant to defray the cost and make the information free for all papers.

With regard to what the public wish to know—they would undoubtedly like (*a*) to have the forecasts issued for a longer period in advance, probably for seasons, and (*b*) that more minute detail should be observed in localizing the regions likely to be affected by rain, and the intensity of the coming fall. At present, however, it has not been found possible to gratify these wishes.

This brings us to the consideration of the principles adopted in preparing the forecast, and the line of work or study which promises to increase their accuracy.

*With regard to the principles adopted.*—They depend mainly upon a recognition of the well-known characteristics of cyclonic and anticyclonic systems, primary, secondary, or V-shaped, and upon the

indications afforded by the three daily observations as to their movements and the questions of their tendency to increase or decrease in area or intensity. The general distribution of pressure (also whether favorable for a continuous prevalence of cold or warm, of dry or wet, currents of air), the effects of such currents when coming from off the sea, or *vice versa*, the relatively rapid motion of air on coasts when compared with that over land, and the variations produced by the seasons on such phenomena are all carefully thought out before preparing the forecasts or issuing warnings, besides the question whether the disturbances are of a "thunderstorm" or other character.

*With regard to the line of work or study most likely to increase the accuracy of the predictions.*—It appears probable that some rearrangement of the districts for which they are prepared, the separation of coast from inland parts of the countries and of the west from the east portions of the Irish districts, is desirable. It is probable, also, that a better knowledge of the upper currents of the air, as shown by high clouds, is necessary, and that a more careful study of the distribution of rainfall under varying types of pressure distribution and at different seasons of the year (distinguishing between the various classes of rains) may improve the forecasts materially. That every effort to bring about such an improvement is desirable must be patent to all—sailors, agriculturalists, and dwellers in towns being all interested in the results.

At present it has been found impossible to institute seasonal forecasts with any reasonable hope of success.—*Frederic Gaster, Chief of Forecast Division.*

## IX.—Berlin Weather Bureau.[1]

The telegraphic reports are received from the *Deutsche Seewarte* in Hamburg, and during the past year another telegram has been received from the Royal Bavarian Central Bureau, containing the reports from the four stations, Zürich, Genoa, Lugano, and Bozen, which have proved very useful.

We use the telegraphic material for the purpose of weather forecasting in the construction of isobars and isotherms, and for about a year I have worked with an assistant (formerly Dr. Sühring, now Mr. Basilius) in plotting lines of equal pressure and temperature variation in twenty-four hours. The method of verification of our forecasts has undergone a great change since its commencement in the spring of 1884. Together with the systematic verification of the forecast, resolved into the elements, I have verified also, as a whole, each forecast according to the *Seewarte* method (I, entirely successful, up to

[1] This is a private business enterprise with its headquarters at the Agricultural High School.—Editor.

V, entirely wrong), in which I have endeavored to take account of the views of the local public as much as possible, and, therefore, to give proportionately more weight to the predictions concerning rain and temperature than to those relating to cloudiness and wind conditions. From these rules the following percentages of success were obtained for the years 1885–'92:

| | I. | II. | III. | IV. | V. | Success. |
|---|---|---|---|---|---|---|
| Winter (Dec.-Feb.)... | 18.2 | 48.1 | 29.6 | 4.1 | 0.0 | 81.1 |
| Spring.................... | 21.6 | 47.6 | 26.4 | 4.4 | 0.0 | 82.4 |
| Summer.................. | 15.8 | 49.1 | 29.7 | 5.7 | 0.2 | 79.2 |
| Autumn.................. | 18.2 | 44.9 | 32.6 | 4.3 | 0.0 | 79.4 |
| Year........................ | 18.3 | 47.4 | 29.6 | 4.7 | 0.0 | 80.5 |

The most favorable month was April, with 83.2 per cent; the most unfavorable, October, with 76.2; and next, July, with 78.9. I would here remark that the forecasts are issued between 2.30 and 2.45 p. m., and apply for the whole of the following calendar day. In single years an increase in the figures denoting success is not evident, and indeed the first years show the greatest success, viz., 1885, 86.7 per cent, and 1886, 84.6 per cent. This arises, however, from the fact that we now attempt to give to the forecasts a more definite meaning, especially to emphasize the expected weather changes, and perhaps, also, our own judgment about the mistakes has become harsher. The continually growing interest of the public is perhaps best shown by the results outside of the Bureau, and I quote below the number of newspapers to which, at the commencement of each year, we were furnishing weather charts and forecasts:

| January 1. | 1885. | 1886. | 1887. | 1888. | 1889. | 1890. | 1891. | 1892. | 1893. |
|---|---|---|---|---|---|---|---|---|---|
| Forecasts......... | 4 | 6 | 6 | 7 | 7 | 16 | 17 | 16 | 17 |
| Weather charts.. | .. | 2 | 4 | 4 | 4 | 6 | 6 | 7 | 7 |

The great increase from 1889 to 1890 is partially explained by the fact that Mr. O. Jesse, who up to that time had made forecasts for four local papers, gave this up in 1889. For the representation of weather charts an attempt was made by us in 1885 to stamp them on type metal, and in the following year the scheme had been so far perfected that it was applicable to stereotyped papers, among which the *Berliner Tageblatt*, which had already for many years printed weather charts by an etching process, adopted ours; this underwent a further improvement in 1889 by the substitution of black for white figures and symbols. Besides this newspaper block, which is ready at 2.30 p. m., we have delivered since May, 1892, daily, except Sunday, at 4.15 o'clock, hektographic weather charts for the local "Urania columns."

I will now, after this long and detailed account of the working of our weather bureau, state briefly the experience we have obtained in our efforts to improve the forecast methods. It appears to me that the efforts toward longer forecasts, even if they are more general, promise

better success than the more exact ones for the next day. In addition to the thorough researches of Van Bebber, upon the typical tracks of minima, it appears to me that a more detailed investigation of Teisserenc de Bort's weather types would be very profitable, and I believe that, to the knowledge of their frequency, duration, change, sequence, etc., my weather charts might contribute somewhat.

As to the wish of the public respecting the forecasts for the ensuing day, it has been my experience that no little importance is attached to the explicitness of the forecast. So, for example, it will not suffice to give the announcement "changeable weather." Here, as everywhere, the greatest attention must be given to the precipitation forecast, and it should be the aim gradually to separate more and more the local from the general rains, and in summer the simple "tendency to thunderstorms" might be replaced by a greater or less "probability of a thunderstorm." Perhaps, a systematic investigation of the variation of the absolute humidity, for which I have for several years been collecting data, might contribute something to this question, although, naturally there are other more important researches. I believe that a more exact knowledge of the recent precipitation distribution is very necessary, for which reason I would urge that in our telegraphic dispatches the tenths of degrees of temperature be replaced in summer by the amount of precipitation, and in winter by the depth of snow. But the subject is too large a one to be exhausted in one letter, so that I fear I have already entered too much into details.—*Dr. E. Less, Director.*

## X.—The Forecast Service in Switzerland.

The creation of a daily weather forecast, based upon synoptic meteorological data, was first undertaken in Switzerland by the undersigned, in the summer of 1878, in a private way. In the year following it was done officially by direction of the Swiss Government; and the issue of a daily weather bulletin was made one of the duties of the Swiss Central Meteorological Institute, established in May, 1881.

As Switzerland is divided into several (3–4) districts whose climatic conditions are essentially different from one another, it was originally planned that the forecasts should be made at several points, based upon a synoptic summary telegraphed to each from the central office. But the observatory at Berne has been the only one to undertake the issue of special forecasts for the surrounding territory; so that, as a matter of fact, the forecasts of the central institute at Zürich have continued to be the only generally distributed prognostications. But in view of the peculiar geographical position of southwestern Switzerland (on account of the influence of the lower

snow-valley), the Central Institute has for several years past issued special forecasts for that district.

The necessity for a forecast service for that part of Switzerland which lies beyond the Alps (Tessin, Engadin) has up to the present been less urgent, mainly because the weather of that district is much more constant than on this side of the Alps. For this reason no special forecast for southern Switzerland is as yet issued, although it would be less difficult than for the northern portion of the country.

The distribution of the forecasts from the central office is made partly through the newspapers and partly to private persons by telegraph, for which latter purpose the telegraph authorities have granted a considerable reduction in rates. The forecasts are usually given out shortly after 2 p. m., and have been made only for the day following. Recently, however, a beginning has been made to forecast for longer periods than twenty-four hours, and not without success; but these forecasts are not yet published.

The forecasts embrace temperature, precipitation, and character of weather. Direction and force of wind are considered only when steep gradients exist, since, with slight gradients, the topographical features of our country govern the local wind movements, which depend almost entirely upon the course of the valleys and character of the ground (lakes, woods, etc.), and their prediction for each little district would hardly be possible, and would be useless.

The forecasts of the central office are verified both at the office itself and by the observers at the meteorological stations at Aarau, Lucerne, and Neufchâtel. In consequence of the topographical peculiarities already referred to, the verification is not applied to each separate meteorological element, but is made according to three classes, wholly verified, partly verified, and not verified, according as to whether the forecast was correct or incorrect with reference to all or only a part of the meteorological elements considered in it. The average found at the four stations is 72 per cent wholly verified, 24 per cent partly verified, and 4 per cent not verified.

The attitude of the public with reference to these forecasts is, generally speaking, a sympathetic one. That the institution meets with confidence is shown by the very numerous special inquiries which reach the central office by telegraph from far and near. It must be stated, though, that in cases of total failure and especially when, in place of the expected fine weather bad weather occurs, the criticism of the public at large or of individuals is a pretty severe one, especially in comparison with that which is in some cases extended to the so-called popular weather prophets. Nor can it be denied that criticism is occasionally colored by a malicious joy at the failure of the so-called scientific prophecy.

The needs of the public, with reference to the forecasts, are not so

much to know whether there will be a slight rise or fall in temperature (leaving out entirely, as above indicated, wind direction and light wind), as to be informed of the general character of the weather. The absolute state of the temperature is only in a few cases (in spring) of special interest, and the same may be said as regards the amount of rainfall (when there is danger of floods).

In most cases only the general character of the weather is under consideration, and consequently the greatest importance is attached to its correct determination. Sudden changes, especially, demand the most attentive consideration. The so-called local influences peculiar to our mountain country are important factors in this connection. Of very great importance is the distribution of the atmospheric pressure on both sides of the Alps. It depends upon this distribution whether or not the influence of a depression moving from north to south will extend to the foot of the mountains. There need be no well-defined wind movement (Föhn) in this case, at least not in the lower regions. The so-called Föhn-effects (otherwise damming up at the mountains and favoring precipitation) make themselves felt even with a comparatively small barometric gradient, and may delay for two or three days, or even entirely prevent, the formation of clouds and precipitation, while at no great distance from our frontier the weather undergoes a radical change.

The study of the influence exercised by the Alpine mountain chain as a climatic factor (which may, perhaps, be also felt in dynamic meteorology) is of the utmost importance for the improvement of the forecasts in our country, and this study requires the most careful fostering of the meteorology of the upper regions through the establishment of good observations at mountain stations.—*R. Billwiller, Director.*

## XI.—The United States Weather Bureau.

The forecasts and warnings of the United States Weather Bureau are based upon a study of reports of observations taken daily at 8 a. m. and 8 p. m., seventy-fifth meridian time, at one hundred and twenty-four regular reporting stations in the United States and nineteen points in Canada. These reports are promptly telegraphed in cipher to the Central Office at Washington and to the more important Weather Bureau stations, and also transmitted by telegraph to the Canadian Central Office at Toronto. During the West India cyclone season provision is made for timely reports by telegraph of disturbances noted in that region.

Instructions covering the making of observations and filing of reports at the telegraph offices allow of no deviation from prescribed methods nor departure from fixed rules. A reference to these methods and rules, and a brief statement of the processes involved from the

making of the observations at the several stations to the issue of the forecasts and warnings at the Central Office, will probably best illustrate the system of the Bureau.

Promptly to the hour and minute the work of observation is begun at each station, and simultaneously the small army of observers performs the several operations pertaining thereto. Within a specified period the enciphered reports are filed at the telegraph offices and placed upon circuits devoted exclusively to their transmission. At 8.45 a. m. and 8.45 p. m., daily, the work of deciphering the reports and charting the data is begun by a force of trained experts at Washington. The average time required for this work is about one hour. Upon the completion of the charts the Forecast Official dictates a statement of the general and special meteorological features presented by the reports, prepares the forecasts for the various districts, and issues such signal orders as the conditions may require. The dictation covering the synopses, forecasts, and warnings is set in type and also telegraphed as it progresses, and at the expiration of the thirty to forty-five minutes required for the performance of this work the utterances of the Forecast Official have been filed for transmission to all points in the United States reached by electric telegraph.

The press associations furnish the daily press with the regular forecasts and warnings, and also transmit special statements or bulletins issued in anticipation of unusual or alarming meteorological conditions. In addition to dispatches transmitted by the news associations, weather and temperature, cold wave, and frost messages are telegraphed at Government expense to specially appointed displaymen and selected points, exclusive of regular observers and stations of the Weather Bureau, as follows:

| | |
|---|---|
| Displaymen of weather and temperature signals | 1,613 |
| Displaymen of cold-wave signals | 174 |
| Displaymen of frost signals | 458 |
| Total paid messages | 2,245 |

In addition to the above, messages for public display are telegraphed to 2,129 railroad stations; messages are telegraphed or telephoned to 620 places; forecasts are sent by mail to 3,065 points; and are delivered by cooperating railroad train services to 1,264 stations. The total number of places to which the forecasts or warnings are sent is 9,323. As before stated, this number represents only regularly authorized display stations, and does not include thousands of persons and places furnished by the various local Weather Bureau offices throughout the country. In addition to the above, and exclusive of regular stations of the Weather Bureau, signals giving warning of dangerous gales are displayed at 121 points on the sea coasts and the Great Lakes.

While the comparative degree of accuracy of the forecasts for defined periods is shown by the percentage of verification, the best proof of their value to the public is the increasing demand for the predictions. Their distribution is now limited by, and coextensive with, the scope of the electric telegraph and telephone.

The regular forecasts of the Weather Bureau are issued from the Central Office at Washington by or before 11 a. m. and 11 p. m., seventy-fifth meridian time, daily. The morning forecast is made for a period of thirty-six hours, and the night forecast for a period of twenty-four hours. In the discretion of the Forecast Official forecasts are made for periods of forty-eight hours. The regular, and what are termed twenty-four and thirty-six hour forecasts, specify the character of the weather, such as general or local and heavy or light rain or snow, fair or clear weather, higher or lower temperature, including terms indicating the amount of the anticipated rise or fall in temperature, and the force, direction, and shifts of the wind for each State or part of State east of the Rocky Mountains. The remaining States and Territories, with the exception of New Mexico and Wyoming, are covered by forecasts issued at San Francisco, Cal., and Portland, Oreg. The morning forecasts are of special value to outlying or country districts, as the messages giving forecasts for the following day can be sent to displaymen and points referred to, and the signals and bulletins displayed without delay. These forecasts also appear in all of the evening papers of the country. When the morning reports indicate unusual or dangerous meteorological conditions, special telegraphic reports are called for and supplementary warnings are telegraphed to threatened districts at the discretion of the Forecast Official. The night, or twenty-four hour, forecasts are of value chiefly in cities and towns where the predictions are disseminated through the medium of the morning newspapers. The early closing of telegraph and telephone offices in the smaller towns and villages prevents a prompt transmission of the night forecasts to outlying districts.

The verification of forecasts for thirty-six hours shown by the tables is determined by the conditions presented by the morning and evening reports of the day succeeding that for which the forecast is made, and the verification of the night, or twenty-four hour, forecasts is based upon the data which are shown on the night charts of the following day. Cold-wave signals are verified if the required fall in temperature occurs within thirty-six hours after the signal is ordered, although the order must specify the period within which the fall is anticipated. A forecast of rain for a State requires for a full verification that seven-tenths of the State shall be embraced within the rain area. When a smaller portion of the State is covered by the rain area the percentage of verification is proportional to the area of

rain. When no rain falls the percentage of verification is zero. Similarly the percentage of verification of forecasts of temperature is proportional to the area of the district included by the temperature changes. Rainfall is considered for the twelve-hour periods ending at 8 a. m. and 8 p. m., and verification of temperature forecasts is determined by the twenty-four hour temperature changes.

The following tables show the percentage of verification of rain and temperature forecasts for twenty-four and forty-eight hours, and also the percentage of verification of cold wave and wind signals during the last two years:

*Percentage of verification of rain forecasts.*

| Year and month. | 24 hours. | | 48 hours. | | Year and month. | 24 hours. | | 48 hours. | |
|---|---|---|---|---|---|---|---|---|---|
| | Number. | Percentage. | Number. | Percentage. | | Number. | Percentage. | Number. | Percentage. |
| 1892. | | | | | 1893. | | | | |
| January | 418 | 65.9 | 0 | ...... | January | 346 | 67.2 | 31 | 68.1 |
| February | 353 | 74.9 | 202 | 53.9 | February | 649 | 82.1 | 18 | 83.9 |
| March | 456 | 74.3 | 92 | 65.5 | March | 704 | 80.2 | 26 | 70.0 |
| April | 334 | 58.9 | 14 | 47.1 | April | 557 | 76.0 | ...... | ...... |
| May | 440 | 72.4 | 7 | 78.6 | May | 234 | 77.6 | ...... | ...... |
| June | 669 | 69.3 | 44 | 21.4 | June | 493 | 74.7 | ...... | ...... |
| July | 512 | 74.9 | 25 | 63.2 | July | 554 | 72.4 | ...... | ...... |
| August | 480 | 73.8 | 10 | 70.0 | August | 638 | 56.8 | ...... | ...... |
| September | 332 | 70.4 | 10 | 74.0 | September | 339 | 73.6 | ...... | ...... |
| October | 198 | 71.9 | 40 | 36.2 | October | 364 | 77.6 | ...... | ...... |
| November | 238 | 83.4 | 0 | ...... | November | 472 | 71.1 | ...... | ...... |
| December | 414 | 67.2 | ...... | ...... | December | ...... | ...... | ...... | ...... |
| Total | 4,844 | ...... | 444 | ...... | Total | 5,350 | ...... | 75 | ...... |
| Average | ...... | 71.2 | ...... | 53.0 | Average | ...... | 73.5 | ...... | 62.6 |

*Percentage of verification of temperature forecasts.*

| Month. | 1891. | | | | 1892. | | | | 1893. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 24 hours. | | 48 hours. | | 24 hours. | | 48 hours. | | 24 hours. | | 48 hours. | |
| | Number. | Percentage. | Number. | Percentage. | Number. | Percentage. | Number. | Percentage. | Number. | Percentage. | Number. | Percentage. |
| Jan | 1,302 | 83.0 | 43 | 90.2 | 1,302 | 85.0 | 22 | 81.8 | 1,302 | 80.9 | 31 | 88.1 |
| Feb. | 1,176 | 84.2 | 75 | 88.3 | 1,218 | 81.1 | 625 | 71.6 | 1,176 | 85.5 | 41 | 72.7 |
| Mar. | 1,302 | 73.0 | 23 | 100.0 | 1,302 | 86.9 | 120 | 73.4 | 1,302 | 84.1 | 48 | 94.0 |
| Apr. | 1,260 | 74.9 | 115 | 87.0 | 1,260 | 75.3 | 25 | 87.2 | 1,260 | 82.5 | ...... | ...... |
| May | 1,302 | 80.3 | 37 | 97.0 | 1,302 | 72.0 | 6 | 30.0 | 1,302 | 82.6 | ...... | ...... |
| June | 1,260 | 72.1 | 57 | 83.5 | 1,260 | 80.5 | 342 | 72.0 | 1,260 | 81.0 | ...... | ...... |
| July | 1,302 | 77.7 | 28 | 85.0 | 1,302 | 82.2 | 15 | 93.3 | 1,302 | 79.3 | 19 | 33.2 |
| Aug | 1,302 | 78.7 | 392 | 79.6 | 1,302 | 78.8 | 42 | 58.8 | 1,302 | 68.4 | ...... | ...... |
| Sept | 1,260 | 84.3 | 135 | 75.1 | 1,260 | 86.1 | 78 | 81.0 | 1,260 | 85.0 | ...... | ...... |
| Oct | 1,302 | 83.4 | 63 | 78.3 | 1,302 | 87.5 | 62 | 77.7 | 1,302 | 81.2 | ...... | ...... |
| Nov | 1,260 | 81.7 | 499 | 71.7 | 1,260 | 84.4 | 31 | 96.8 | 1,260 | 87.9 | ...... | ...... |
| Dec. | 1,302 | 87.3 | 199 | 76.3 | 1,302 | 82.7 | ...... | ...... | ...... | ...... | ...... | ...... |
| Total | 15,330 | 960.6 | 1,666 | 1,012.0 | 15,372 | ...... | 1,368 | ...... | 14,028 | ...... | 139 | ...... |
| Average. | ...... | 80.0 | ...... | 84.3 | ...... | 81.9 | ...... | 73.4 | ...... | 81.6 | ...... | 78.1 |

*Percentage of verification of wind signals.*

| Month. | 1891. | | 1892. | | 1893. | |
|---|---|---|---|---|---|---|
| | Number. | Percentage. | Number. | Percentage. | Number. | Percentage. |
| January | 87 | 81.7 | 225 | 84.1 | 217 | 72.3 |
| February | 116 | 69.7 | 162 | 69.6 | 191 | 83.2 |
| March | 114 | 82.1 | 174 | 87.1 | 180 | 76.3 |
| April | 91 | 67.0 | 239 | 84.1 | 338 | 83.7 |
| May | 76 | 73.0 | 232 | 76.4 | 225 | 83.9 |
| June | 20 | 41.5 | 58 | 67.4 | 128 | 70.4 |
| July | 65 | 58.9 | 43 | 56.1 | 36 | 63.9 |
| August | 14 | 41.0 | 42 | 68.7 | 94 | 82.0 |
| September | 50 | 62.6 | 126 | 62.1 | 143 | 68.0 |
| October | 165 | 69.9 | 162 | 73.2 | 336 | 74.5 |
| November | 187 | 71.4 | 343 | 82.2 | 300 | 71.5 |
| December | 96 | 76.9 | 170 | 75.5 | ......... | ........... |
| Total | 1,081 | ........... | 1,976 | ........... | 2,188 | ........... |
| Average | ......... | 71.1 | ......... | 77.6 | ......... | 76.6 |

*Percentage of verification of cold-wave signals.*

| Month. | 1891. | | 1892. | | 1893. | |
|---|---|---|---|---|---|---|
| | Number. | Percentage. | Number. | Percentage. | Number. | Percentage. |
| January | 188 | 54.8 | 386 | 67.0 | 639 | 56.2 |
| February | 378 | 70.1 | 311 | 62.5 | 295 | 73.5 |
| March | 114 | 54.4 | 120 | 85.5 | 224 | 84.0 |
| April | ......... | ........... | 61 | 52.7 | 150 | 55.0 |
| October | 20 | 40.0 | ......... | ........... | 38 | 60.5 |
| November | 179 | 68.8 | 215 | 63.4 | 229 | 65.3 |
| December | 230 | 70.2 | 185 | 48.1 | ......... | ........... |
| Total | 1,109 | ........... | 1,278 | ........... | 1,575 | ........... |
| Average | ......... | 65.2 | ......... | 63.6 | ......... | 64.7 |

While a thorough knowledge of general meteorology, and of the conditions peculiar to the various districts or localities for which the forecasts are made is a recognized qualification, the forecaster must possess the ripe judgment gained by experience, and the confidence and aptitude which nature alone bestows, in order to become eminently successful in the practice of weather forecasting. The principles upon which the forecasts depend are embodied in the application of these necessary qualifications to a solution of the problems presented by the weather maps. The tabulated data show the degree of success attained in predicting the several changes or character of weather covered by the forecasts. Rain or snow forecasts are admittedly the most uncertain and are the forecasts which yield the lowest percentages of verification; yet this class of predictions is undoubtedly of the greatest importance. If, therefore, rain can be accurately predicted seven times out of ten it may be safely asserted that we are able to predict rain. As regards fair weather forecasts the percentage of verification is 15 to 20 per cent higher; we may, therefore, also claim success in forecasting fine weather. It is safe to say, in this connection, that the failures in rain forecasts are largely

confined to what are termed "local rains," and that general and heavy precipitation is in a much larger percentage of instances anticipated. The same may be said of the forecasts of temperature; in this class of forecasts marked and general changes are rarely unpredicted. The success attained in wind signals is scarcely represented by the percentage of verification, as in many instances dangerous winds which out-going vessels would encounter will prevail within a few hours' sail of the port at which the signal is displayed without a justifying velocity at the station. The success in verifying wind signals, as shown by the table (about 77 per cent), proves, however, that we are able to predict wind storms for specified points with a marked degree of success.

In fair weather the public desires to know when rain or snow may be expected, and when rain or snow is falling the demand is confined to enlightenment as to the duration of the storm. The public wishes to know when to prepare for cold waves and frost, and requires forecasts, not a statement of existing conditions. The interests reached and benefited by good forecasts are not confined to any business, profession, or class. Commerce and agriculture, dealers and handlers of all description of goods and produce subject to injury by the elements, the well and ill, all have material or personal interests which render valuable a knowledge of the weather of to-morrow. At the present stage of the science of meteorology the character of the weather of to-morrow can be regularly and successfully anticipated from the morning reports more than eight out of ten times. In cases where the changes are marked the degree of success is unquestionably greater.

As the forecasts for forty-eight hours are optional with the Forecast Official, the percentages given do not represent results comparable with the predictions made for shorter periods; neither do they show the degree of accuracy that is possible in forecasts made regularly for the longer periods.

The energies and resources of the Weather Bureau are now being devoted to attempts to determine and adopt methods calculated to improve the forecasts. Efforts will be made not only to obtain the best forecasting talent, but to solve by well directed scientific studies and investigation many of the perplexing problems which now confront the forecaster.—*Major H. H. C. Dunwoody, U. S. A., Chief of Forecast Division.*

## SECTION II.

# RIVERS AND FLOODS.

### 1.—FLOODS OF THE MISSISSIPPI RIVER, WITH REFERENCE TO THE INUNDATION OF THE ALLUVIAL VALLEY.

WILLIAM STARLING.

The Lower Mississippi derives its main supply of water from three different sources—the valleys of the Ohio, the Upper Mississippi, and the Missouri. These regions have many points of dissimilarity. The valley of the Ohio belongs to an early geological period, the upheaval of the Appalachian chain having occurred at the close of the Paleozoic time. The valley of the Upper Mississippi was partly contemporaneous with that of the Ohio, while a part is of later date. The valley of the Missouri is of comparatively recent origin. The Rocky Mountains were hardly in existence when the Ohio was already a full-grown and even an old river. The place of the Missouri of to-day was then occupied, first by a prolongation of the Gulf of Mexico, afterward by a series of great fresh-water lakes. Finally, on the completion of the elevation of the Rocky Mountains, in the late Tertiary period, the Missouri assumed something like its present shape, subject, of course, to the subsequent changes of the Glacial, Champlain, and Terrace epochs, by which its full development as a river was completed, in common with that of the other tributaries and of the great alluvial valley of the united stream.

The physical and climatic features of these valleys are as various as their origin. The Missouri Basin is much the largest of the three, containing about 541,000 square miles. The Ohio Valley is not half so great, possessing a watershed of only 202,000 square miles. Smallest of all is the valley of the Upper Mississippi, with an area of only 171,500 square miles. These grand basins are visited by rainfalls which are of great diversity. In the Missouri Basin the annual downfall is given by Humphreys and Abbott as only 20.9 inches, and of this it is estimated by the same authorities that only 15 per cent is actually turned into drainage. The Upper Mississippi region has a rainfall of 35.2 inches, of which 24 per cent makes its appearance in the channel of its river. In the Ohio Valley the quantity of rain

which annually descends is 41.5 inches, and of this, too, 24 per cent is turned into the river. Later observations have somewhat modified these figures, but they will answer our purpose. Hence, the great Missouri Basin, with its enormous area, but with a scanty rainfall and an absorptive soil, and with drying winds, contributes less to the main river than the Ohio, with its rainy and wooded western mountain slopes and its sharp declivities; and the Upper Mississippi less than either. The respective proportions are as 50, 38, and 33.

The course of the Ohio is far more southerly than that of either of its sister streams. Its extreme northern tributaries reach hardly higher than latitude 42°, while to the southward it ranges as low as latitude 34°. Its highest sources are in the low range of the Appalachians, and it rarely encounters a cold climate. Its snows thaw soon and its mountains catch the warm winds from the Gulf of Mexico. Its greatest rainfall is in January, February, and March, therefore its floods are early, coming sometimes in January, generally in February, though sometimes later. There is a record of a considerable flood in August, 1875. Its greatest tributaries are on the left, eastern or southern side, heading in the Alleghanies, the streams on the opposite side being short and comparatively important. The two capital tributaries, the Tennessee and the Cumberland, have an extreme southerly range and a great rainfall, and pour down an immense volume of flood water. They never reach any considerable height after April.

The Upper Mississippi runs almost south, and its extreme northern sources are frequently locked in ice until late in the spring. Its southerly tributaries often suffer considerable freshets at a much earlier date, but they are of limited extent, and it is but seldom that a flood of any consequence appears earlier than April. Its greatest rainfall is in May and June.

Most of the feeders of the Missouri have their origin on the eastern slope of the Rocky Mountains. The principal rise is caused by a combination of melting snows and late spring rains, and usually reaches Saint Louis in May or June. There are frequently partial freshets from early rains in the lower part of the valley in February or March, but they never attain the dimensions of the "June rise," as it is called. Very little water falls in the greater part of this immense valley in the winter months—a good deal in April, but the most in May and June.

It must not be forgotten that the Lower Mississippi, below the confluence of the three great component streams, receives the waters of several large rivers, some of them heading in regions of heavy rainfall, with a very great percentage of drainage, and consequently contributing, at times, enormous volumes of water. Two of these, the Arkansas and White rivers, discharge into the Mississippi through a

common basin. They have, jointly, a watershed greater than that of the Upper Mississippi, and annually pour into the great trunk stream more than half as much as the Missouri. The Saint Francis and Yazoo each contribute about one-fourth as much. Red River, while a very important stream, yet enters the Mississippi so near its mouth that its floods are of only local importance. Moreover, a considerable part of them passes out through the Atchafalaya.

The Ohio, Upper Mississippi, Saint Francis, and White rivers are non-sedimentary streams. They flow mostly through hard formations and stable beds, and at low and medium stages their waters are clear. The Missouri, Arkansas, Yazoo, and Red rivers are always more or less muddy, flowing, as they do, in the lower portion of their course, through beds of their own deposits. The qualities of the sediments which they bring to the great river are different. That of the Missouri is mostly light and loamy, and thus is capable of being transported for very long distances, as will appear from the fact that the quantity of matter carried in suspension at New Orleans is much greater during floods from the Missouri than at other times. The sediment from the Arkansas is usually of a reddish color, as is well known to the pilots and other river men, all of whom can tell, by a glance at the waters, whether the Arkansas is in freshet.

From causes which will appear hereafter, the western rivers, the Upper Mississippi, the Missouri, the Saint Francis, White and Arkansas usually act together. The Ohio and its tributaries are governed by different conditions. It has never occurred that all these streams were in extreme flood at the same time. Such an ominous conjunction would produce a discharge of more than 3,000,000 cubic feet, which would be greater by one-half than has ever been known. But it has often happened that an extreme flood from the Ohio has met a moderate freshet from the western streams, or that a high May or June rise from the latter has found the Ohio at more than a medium stage. In either of these cases, great floods may and do occur in the lower river. In fact, it is quite possible for a very great flood in either the eastern or western system, combined with a merely average stage in the other, to produce a very high water below the mouth of the Arkansas. The usual order of floods from the several tributaries is as follows: the Ohio, Cumberland, and Tennessee, all together; then the Upper Mississippi; then the Missouri, with probably the other western rivers.

It is often affirmed that the principal cause of floods is the melting of the winter's ice and snow. In the case of the Ohio this statement, as a generality, must be denied, and it is believed that this denial may be extended to the other rivers. Certainly, it may to the southern streams, including the Arkansas. In point of fact, some of the greatest snowfalls ever recorded in the Ohio Valley have dis-

appeared without producing any considerable effect, and some of the greatest floods have occurred when there was no snow on the ground. The most potent agent in producing floods has been excessive rainfall. This assertion does not exclude the action of snow where it exists. On the contrary, it cooperates with it most powerfully. A deep snow, passing off with a warm and heavy rain, of course greatly augments the effect of the latter, and that too at a very critical time. Every fraction of an inch added to a considerable rainfall increases its effective volume for drainage more than proportionately; for instance, in a dry season, an inch of rain will not much more than be absorbed by the ground, but if two inches fall the additional inch will nearly all turn to drainage, and of three inches two will be available for river water. Thus, a three-inch rain will be doubly as damaging as one of two inches, and infinitely worse than one of a single inch.

The heaviest, most sudden, most violent, most extensive, and most dangerous rains that occur in the Ohio Valley are those accompanying the cyclonic storms which originate or have their fullest development in the vicinity of the Gulf of Mexico. These, as is well known, generally first assume formidable proportions within the territory of the United States in southeastern Texas, and then follow the Ohio Valley to the Great Lakes, making their exit at the mouth of the Saint Lawrence River. They are usually accompanied by very low barometer, southerly winds, much thunder and lightning, and deluges of rain, which last is not merely caught by the mountain ranges that intercept and, as it were, strip the clouds, but also falls with equal impartiality on all parts of the lowlands. A considerable flood has been known to result from two of these storms, each distributing about three inches of rain over the Ohio Valley, at an interval of about a week apart. The season was March to April. There was little snow, and the rivers were decidedly low. These storms are supposed, I believe (though here I think I am speaking Latin before clerks), to follow the direction of the prevailing current of the upper air, and consequently generally travel somewhat from southwest to northeast, skirting the western slope of the Alleghanies. Their path does not usually include the upper waters of the rivers of the western system, though it may encounter their lower portions. They have been known to prevail for weeks, one following the other at intervals, two or three in a month, literally drenching the whole country through which they passed, as probably in the famous season of 1867, and certainly in the more famous one of 1882. In the latter year, the rainfall in the Ohio Valley for January was 60 per cent more than the normal for the month. In the Cumberland and Tennessee valleys it was *three times* the average. In the Lower Mississippi Valley it was more than double the mean. In February, for the Ohio Valley

the excess was 70 per cent; for Tennessee, 65 per cent; for the Upper Mississippi, 50 per cent. The extreme height of the flood was reached at Cairo on the 26th of February. In February, 1884 (flood month), Ohio Valley, 70 per cent excess; Tennessee, 70 per cent. There was also much snow on the ground. In January, 1890, Ohio Valley and Tennessee, 35 per cent excess; in February, 60 per cent; in March, 40 per cent. There was excessive rain in the valleys of the Arkansas and White rivers, especially the latter, keeping it near extreme flood nearly four months. The flood in the lower river was in March and April. In 1892 the Ohio was at a moderate stage throughout. The flood came from the western rivers, and culminated at Cairo on the 27th of April. Before this had time to recede it was caught by another which reached its maximum on the 25–26th of May. The rainfall for April in the Upper Mississippi Valley was 80 per cent in excess of the mean; for the Missouri Valley, 80 per cent. In May, Upper Mississippi, 80 per cent excess; Missouri, 60 per cent; in the valleys of the Arkansas, White, and Saint Francis, 87 per cent. There was a great flood at Saint Louis, the highest since 1858, and a very great one at Fort Smith, the highest on record, and at Little Rock, the greatest, I believe, except 1833.

Thus, there are two classes of floods which afflict the alluvial plain of the Mississippi—the early floods which proceed mostly from the eastern rivers, and the late, which owe their origin principally to the western streams. The former usually reach their height in the lower valley in March, the latter in June. Sometimes there occur very high waters of a third class, intermediate between the two, in which a late rise from the Ohio meets an early freshet from the Upper Mississippi and Missouri, accompanied, as usual, with sharp rises from the lower streams. Such floods culminate in April or May. It is a question which of these is most dreaded by the dwellers in the alluvial region. The March floods are frequently very great in volume, come up very rapidly, and take place at a very inconvenient and inclement season. They are usually accompanied by very high, cold and persistent winds, often with chilling rain or sleet and plenty of mud and general discomfort. Now, if there is anything which levee engineers dread, it is storms when the water stands at a very high stage against their levees. The river at such times is two miles, or more, wide. There are long stretches over which the wind has full sweep for eight or ten miles up or down stream, or in "old river lakes," and a February or March "norther" sometimes gets up a formidable sea, breaking with great force clean over the levee and menacing it with speedy destruction. Provision is made against this danger, to some extent, by sodding the slopes of the levees, by giving them a long and gentle incline towards the water, and in the most exposed places by revetments or breakwaters of plank. It would be

easy enough to make an effectual defense, as is done in Holland, Germany and Italy, by facing the front of the dikes with stone, but that is expensive, and the Mississippi levees have not yet reached the stage of development when such a course is practicable. They are still struggling toward completion. Severe and prolonged storms, however, will cut through even a long and well-sodded slope, and plank are not always to be had in an emergency. Moreover, the levees are in a state of transition, and frequently the sod has not had time to grow, and it would not be proper to erect permanent and costly defenses when fresh accessions of earth have to be made every two or three years. So resort must be had to temporary expedients for protection against the violence of waves, and chief of these are what are sometimes improperly called *sand bags*. Improperly, because the less sand there is in them the better. They are strong and new sacks filled, by preference, with the heaviest and stiffest clay that can be had, though, generally, use must be made of the first material that comes to hand. These must be filled and placed in the teeth of a howling "blizzard," every blast of which cuts through the men, wet to the skin as they are with spray or rain. To the novice it always seems wonderful that earthen dikes can be held at all against such heavy odds, and yet it is but seldom that they are lost from this cause.

The engineer, then, would rather undertake to hold his levees in May or June, when the sun is warm, the air genial and mild, the earth dry and the days long. Then his men are cheerful and willing, and, if they are negroes, sing all the day as they work. But the planter dreads a summer flood. Should the levees break and he be overflowed in March, the river will probably subside in time for him to make a crop. But if such a misfortune happen in May or June, it will be too late to calculate on a full return, and he must either lose the season altogether or incur the expense of replanting with a prospect of only half a crop, or thereabouts.

Overflow is not the only calamity that a planter dreads from a flood. Even with the best constructed levees a vast quantity of water leaks through the porous natural soil beneath the base of the embankment, invades the roots of his growing corn and cotton, and even rises in the furrows or perhaps above the ridges, thus effectually drowning out his crops. This seep water, as he calls it, is an unmitigated evil. Inundation water brings with it fertilizing silt. Seep water has been stripped of all this by filtration through the ground. It is sterile, stagnant and foul. It destroys cotton or corn, and seems really to retard the recovery of the land even after it has disappeared. Ditching will not always get rid of it. This damage, too, is far greater when the season is well advanced, for very similar reasons. Fortunately, seep water usually affects only the ground immediately adja-

cent to the levee, and generally only the low-lying parts of that. Moreover, it does not injure grass, so the planter may turn his low grounds into pasture.

The highest floods that have ever prevailed in the Mississippi proceeded mainly from the Ohio, and culminated in March. These were in 1882 and in 1884, which are believed to have brought down a greater quantity of water at one time than any of which we have an accurate account. The floods from the western rivers, while some of them have been attended by a discharge not very much less than these, have usually been more remarkable for their duration. Of course, it is a matter of the highest consequence to forecast, if possible, the progress of a flood, and this can best be done by comparison with the records of past experience, to see if perchance any analogy can be traced which may lead to probable inferences for the future. With this view, the progress of the different floods has been graphically indicated by curves or hydrographs for the different stations, and much study has been given to them. On the whole they are very disappointing. As a general rule there is very little resemblance between the various floods of the Mississippi, even between those of the same origin. With a few exceptions there is hardly any analogy to be traced between the hydrographs of any two floods at whatever interval. The most remarkable of the exceptions alluded to is that of the three years, 1882, 1883, and 1884, which exhibited a great similarity. All came principally from the Ohio; all culminated at Cairo, from the 22d to the 27th of February, at a gauge height varying from 51.79 to 52.17, being the highest on record; and neither was much complicated with the western rivers. The floods of 1892 and 1893 also presented a general similarity, each culminating in the lower river about the first of June.

It might be thought that it would be an easy matter to predict from a given rainfall in the several valleys the stage to be reached at the different points along the course of the main river, but in reality it is a very complicated problem. It has already been seen that the ratio between downfall and drainage is very diverse in the several watersheds, and even in any one region this rate differs from itself by a very wide range of discrepancy, according to season and circumstances. A rain of say three inches in January does not by any means signify the same thing as a rain of three inches in June. In the one case the ground is frozen, the skies are mostly cloudy, the days are short, the air is cold, the trees are bare of foliage, the earth without any cover of vegetation. It is well known that taking the average of a whole year there is no very great difference between rainfall and evaporation; but the ratio between these two elements for the several months is widely diverse. Observations made during a period of 143 years, at a station in Holland, on the border of Haar-

lem Lake, show that during November, December, and January the rainfall is about four times the evaporation. In May and June the evaporation is about double the rainfall. In March the two are about equal. The course of the seasons is different in this country, and in the Mississippi Valley, at least, would seem to be about a month later.

Now, in June, the earth is dry, porous, and receptive, the sun hot, the air has greater capacity for moisture, the days are at their greatest length, and the whole surface of the ground, wild or cultivated, woodland, field, plantation, or meadow, is covered with leafage. It is, therefore, often found that a storm which would have produced a calamitous freshet in winter or early spring, raises the rivers but a few feet in summer. Hence it is, for one thing, that spring is the season for floods. It is not that the rain is so much heavier, or that the quantity of snow on the ground is so great, but that whatever does fall is in a great measure converted into river water. Those engineers who have investigated the question of water supply for cities have found that the proportion of rainfall which finds its way into the water courses is, in January, about nine-tenths; in June, four-tenths; in August, one-tenth.

There are many other considerations which greatly influence the height of floods. One of them is the condition of the ground as to moisture when the decisive rainfall occurs. It may be that this is already saturated with previous rains or by melting snows, so that it will not readily absorb any more, and this independently of season. It has already been remarked that a sudden and heavy rain, a "cloud burst," as it were, produces rises in the streams out of proportion to the actual quantity of water which falls, and two or more of these, with only a short interval between, may bring about a disastrous flood when the same rainfall, spread over a month, would have been comparatively harmless.

A very important element to be considered, as regards the stage to be attained, especially in the lower trunk, is the height at which the principal rise finds it. It is a proverb among the denizens of the Mississippi Valley that a full river on the first of January portends an overflow in the spring. This simply signifies that it is an unfavorable prognostic, so far as it goes, for the March rise to find the lower river already occupied by a great volume of water. Suppose a heavy storm in the Ohio Valley to produce a rise of 25 feet at Cincinnati, Nashville, and Chattanooga. It is obvious that it makes a great difference to the people of Greenville, in Mississippi, whether this freshet finds the river at that point already standing at 35 feet or 15 feet.

A second element of great consequence is the duration of the rise. A freshet which rapidly goes up to 50 feet at Cairo and then as rap-

idly falls, as in 1886, is less formidable, and will actually reach a less height at lower stations than one which is a foot or two lower at the head of the alluvial basin at Cairo, but remains at that stage for a week or more.

A third controlling element of a flood in the lower river is the local rainfall in the southern portion of the basin, which is sometimes so great as to keep that part of the river, for weeks, higher by several feet than the normal relation between the gauges would prescribe. The rainfall in the lower part of the valley is sometimes extremely heavy. In the Yazoo Basin the rainfall for April, 1874, was 22 inches. In 1893, the present year, the rainfall at Helena, in May, in a single week, was 14½ inches, and the quantity of water which fell in the Saint Francis Basin was sufficient to maintain the stage at Helena above 45 feet on the gauge for about two weeks, when its normal stage should have been 42, or less.

The rate of travel of the flood wave is a subject of much interest and importance, and it might be thought that it would be very easily predicted by a reference to the experience of former years. It is liable, however, to several perturbations. It is influenced by slope and by height of stage, and is complicated by the intervention of tributaries and reservoirs. A word as to the latter.

While a great part of the alluvial plain of the Mississippi, from Cairo to the Gulf, is defended by levees, yet there are two large territories which are nearly destitute of such protection. These are the great basin of the Saint Francis and the lesser plain which spreads out between the hills and the Mississippi, at the confluence of the White and Arkansas rivers with the trunk stream. The upper part of the latter district will soon be shut off by levees, when its disturbing influences will in a great measure cease, except as complicated with the action of the great tributaries which empty into it. The Saint Francis Basin is likely to maintain its present condition for several years. In fact, few active steps have yet been taken for its reclamation. There are several such great bottoms in the Mississippi Valley, defined by the approach of the tertiary hills on either side, each having its characteristic tributary stream, but most of them have been inclosed by levees, and need not be considered with reference to our present subject. The Saint Francis Basin, however, exercises a very important influence upon the flood stages of the river in its front and for some distance below it.

This basin, or bottom, is merely a large tract, some 6,000 square miles in area, of alluvial land, intersected, however, by one or two ridges of an older period, and bounded by the Mississippi on the east, and by the hills called Crowley's Ridge on the south and west. The minor features of this basin were much disturbed by the earthquake of 1811, which exhibited its greatest activity in the neighborhood of

New Madrid, on its eastern border. Crowley's Ridge forms a continuous chain, abutting upon the river at Helena, and is far above the level of the highest waters of the Mississippi. The bank of the basin is low and liable to overflow, except where protected by a few local levees. At a stage of about 42 feet on the Cairo gauge the water begins to pour over the bank below New Madrid and to fill up the "sunken lands" and other depressions in the bottom. As the river rises the overflow becomes greater and greater, and the water begins to drain off through the water courses tributary to the Saint Francis, and finally to inundate the ridges and spread broadcast over the whole basin. It then moves slowly southward, impeded by its own shallowness, by forests and canebrakes, and by three railroad embankments, until it reaches the hills, when it is turned eastward, being discharged into the Mississippi in the vicinity of the mouth of the Saint Francis just above Helena. The bottom then acts as a vast reservoir, receiving at the upper end and discharging at the lower a volume equal to about one-fourth of the entire contents of the Mississippi. It is obvious that the effect of this action will be to depress the flood line in the main river opposite the upper portion of the basin. It appears also to the great majority of engineers that it raises the flood line near to and below the mouth of the Saint Francis. Not that the total discharge is materially greater than it would have been if there had been no basin at all, but by the loss of energy incurred in losing and restoring the vast volume of water. When the latter is returned it is poured into the Mississippi with a sluggish velocity and at an unfavorable angle, so that it acts as a clog upon the latter, which has all that it can do to transport its own mass against the resistance of friction. Therefore, an engorgement must ensue until the united waters acquire head enough to confer the requisite velocity.

What is still more clear is that the crest of the flood is greatly retarded in its passage from Cairo to Helena. At the ordinary rate of movement of flood waves, even at lower stages, the passage should occupy, in a confined river, only about five or six days. Under existing conditions it usually takes from eleven to fifteen days. In 1890 it consumed seventeen days, and in 1891 it took twenty-two days. This prolongation by so many days of the time of trial is as endurable to those subjected to it as a like number of hours would be in a dentist's chair or on a surgeon's table. Not only is the danger increased in direct proportion to the time of exposure, but additional hazards are incurred in the softening of the earth of the levees and undergrounds, the gathering volume of seep water, and the liability to be caught by other floods supervening on that which is present.

The engorgement at Helena produced by the return-flow from the Saint Francis Basin had formerly a parallel, before the closure of the

Yazoo Basin, at the foot of the latter at Vicksburg, and another at the mouth of Red River, acting as the receptacle of the flood waters of the Tensas Basin. The engorgement is only local; the increased height and slope conferring a more than average velocity, which soon "flattens out" the flood wave, so that 100 miles below Helena it would signify little whether the Saint Francis Basin were closed or not, were it not for the intolerable retardment of the flood.

In applying the records of past observations to the purpose of deducing therefrom the probable stages to be attained by a flood just coming in sight, it is indispensable to have an accurate knowledge of the changes that have occurred and that are continually occurring in the lower river, especially in the way of levee building. During the period from 1882 to the present, and especially since 1884, there has been tremendous progress made in this direction, by which the whole high-water regimen of the Lower Mississippi has undergone a radical alteration. It is very difficult, therefore, to derive much instruction, in the forecasting of flood stages and periods, by a direct comparison of the records of years anterior to 1885, and below Arkansas City, anterior to 1888. This is the more to be regretted, for 1882, 1883 and 1884 were undoubtedly three of the greatest floods that ever occurred, particularly the first and last. The principal changes that have occurred are the complete closure of the Yazoo front in 1884–'85, the rebuilding of the Arkansas levees of the Tensas front in 1886–'87, and the raising and strengthening of all the different works of this class which has been constantly going on ever since. It is necessary to bear these alterations continually in mind, in attempting to reason from the older data, else we shall make serious mistakes. In attempting, again, to apply analogies based upon any great flood year, we must know the circumstances which prevailed in that year, especially whether any crevasses occurred, and if so, when and how large, and how extensive was their influence. For instance, in 1882, in some places, half the water of the river went over the banks. In 1890 there were many localities where one-fourth of the discharge was lost in the same way. In 1892 two-thirds of the portentous outpour of the Arkansas—more than half that of the Missouri at full flood—never reached the Mississippi at all, unless it may have been through the Red River, but went around the head of the Tensas system of levees. It is want of acquaintance with these details which has gone so far to cause the phenomena of the Mississippi, in time of high water, to be regarded as anomalous, and has caused the failure of many predictions.

It is evident, then, that if any instruction is to be derived from the records of the past, it must be as the result of attentive study, and that any conclusion drawn from such records must be in the nature of a calculation in which all the perturbing influences must be taken into account. There are several methods which promise a hope of

success in this way. If discharge observations have been systematically taken at any point, for instance Arkansas City, and a certain ratio of progression established between the discharge and the height of the gauge, then if the probable discharge can be predicted the flood height may become known. Again, if we can find any gauge which has not been subjected to disturbing influences, but has remained unaltered for many years, and if we can trace any parallelism or any known relation whatever between it and the gauges below, at stages less than the highest, then by analogy the relation may be extended to extreme heights. Such a gauge is that of Cairo. If, therefore, the stage at Cairo be given, or can be calculated, the heights of the lower stations may be estimated. Now, it is possible from close observation of the rises in the great tributaries, or even from the reports of the rainfall, to make a pretty fair approximation to the stage to be reached at Cairo by any flood, and the probable discharge can be estimated from the stage and other circumstances.

Discharge observations have been taken at several points with considerable care, and, though scattered and fragmentary, they extend over a period of many years. So far as any hope is concerned of deducing a regular relation between discharge and stage, they are extremely disappointing, for they are discrepant and apparently capricious beyond measure, and frequently show that the greatest volume passes at a stage much below the maximum, even several feet below. Some of the disturbing causes are known and calculable. Others are still involved in much obscurity. In the present state of our knowledge, then, not much assistance is to be derived from this method.

The relations between the several gauges have been made the subject of study by several engineers, particularly by Colonel Suter and Captain Rossell, of the Corps of Engineers, United States Army, who have drawn many interesting conclusions. As an example of the application of this method it may be said, roughly speaking, that under ordinary circumstances a stage of say 48 feet on the Cairo gauge corresponds to about 46.5 at Helena, 49 at Arkansas City, 44 at Greenville, and 48.5 at Vicksburg. Of course, these figures are subject to modification in all sorts of ways, by the behavior of tributaries and reservoirs, by diversities of slope, by duration of flood, and by other causes, all of which must be taken into account if an estimate is to be at all accurate—and even half a foot is a matter of serious consequence at the top of a great flood. The local "river prophets" have acquired considerable skill in this sort of prediction; and when once the extreme height at Cairo has been reached, or plausibly calculated, they can foretell the progress of the flood down stream within pretty narrow limits. As to general prognostications, they also have a number of saws, such as the one already quoted,

that a full river on the 1st of January indicates an overflow in the spring. Another is, that an "open" or mild winter forebodes high water, and a severe winter low water. So far as spring floods are concerned, this view is rational enough. Warm winters imply southerly winds and Gulf storms—cold ones, high barometer and winds from the north and west. As to summer floods, they depend on more remote causes.

The most wearisome, exhausting and dangerous floods are those which are composed of a succession of rises, each one catching its predecessor before the latter has had time to subside. The beginning of a flood wave travels very fast. When the river is 50 feet at Cincinnati and 25 feet at Cairo the slope is steep and the topmost layers of water move at a great speed. On the contrary, the rate of recession is slow. When the river is 25 feet at Cincinnati and 50 feet at Cairo the movement of the wave is sluggish, and it is easily overtaken by a sharp freshet. In this it is aided by the tributaries near the main stream, fed by the rainfall in the interior valley, which pour forth their floods almost instantly, and check the fall in a very short time. An inspection of the hydrographs of say Cairo and Vicksburg shows a series of elevations and depressions in the former where the latter exhibits an almost unbroken rise. The great number of the tributaries of the Mississippi makes it peculiarly obnoxious to these incidents. When the Ohio, Cumberland, and Tennessee have begun falling at a good rate, "it is pretty hard," as Sir Lucius O'Trigger would say, if a freshet can not come from the Upper Mississippi or the Illinois and keep the water up at Cairo till the eastern rivers have got their second wind, or failing that, if the White and Arkansas can not give it a fillip, just to keep the ball in play. I hope none of my audience knows the feeling of hope indefinitely postponed that seizes upon the sufferer who has been "fighting high water," as it is very appropriately termed, for two months, and who has been for two weeks anxiously waiting for the fall at Cairo to reach him, on hearing that there has been a rainfall of 6 inches at Fort Smith and Little Rock, and a rise of 14 feet in twenty-four hours.

The damage done by overflows in the Mississippi Valley is generally much overrated. The loss of life is usually absolutely nothing. Unless one is unfortunate enough to live actually just behind a levee when it breaks, or to be standing upon it, there is very little danger. The reason of this is that the drainage is excellent, and all toward the back country, and that the fall of the water surface is very rapid, the water spreading in all directions, and filling up the swamps very slowly.

## No. 2.—FLOOD PLANES OF THE MISSISSIPPI RIVER.

J. A. Ockerson.

A resolution of Congress, approved in February, 1871, provides that water gauges should be established and "daily observations made of the rise and fall of the Lower Mississippi River and its chief tributaries" at nineteen specified points, eleven of which are on the Mississippi River between Saint Louis and the Gulf of Mexico.

These gauges were established in the fall of 1871, and from that time to the present the records, with a few exceptions, have been continuous and the information derived from them becomes more and more valuable with the lapse of time.

Prior to 1872 the records of high water were kept at several points on the river, extending back to near the beginning of the present century. Some of these earlier records are accepted as authentic. The best of them are those of Saint Louis and Natchez. The chief difficulty found in verifying them is the lack of well-defined, fixed reference points, which alone could prove to the entire satisfaction of the engineer that the results recorded are correct. In their absence we are compelled to accept the records kept by careful, conscientious observers, with the feeling that they are probably nearly correct.

In 1882 several new gauge stations were added by the Mississippi River Commission, and others have been added by the United States Weather Bureau, so we now have forty-five gauges between Saint Paul, Minn., and the Gulf where daily readings are made. The location of these gauges is shown in the following table:

*Water gauges on the Mississippi River.*

| Location. | Distance from the Gulf of Mexico. | Gauge zero above mean Gulf level. | Gauge readings. | | Bank-full stage. |
|---|---|---|---|---|---|
| | | | Lowest. | Highest. | |
| | *Miles.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Saint Paul, Minn | 1,969 | 683.33 | 0.1 | 19.7 | ........... |
| Hastings, Minn | 1,942 | 669.53 | −0.7 | 18.0 | ........... |
| Winona, Minn | 1,844 | 639.08 | −1.3 | 16.9 | ........... |
| LaCrosse, Wis | 1,812 | 627.45 | 0.0 | 17.4 | ........... |
| North McGregor, Iowa | 1,737 | 603.62 | 1.7 | 15.8 | ........... |
| Dubuque, Iowa | 1,678 | 583.34 | 0.9 | 21.8 | ........... |
| LeClaire, Iowa | 1,588 | †554.00 | 0.0 | 14.5 | ........... |
| Rock Island, Ill | 1,571 | 541.09 | −0.8 | 19.4 | ........... |
| Muscatine, Iowa | 1,542 | 529.30 | −0.1 | 17.3 | ........... |
| Keokuk, Iowa | 1,443 | 475.60 | −0.8 | 21.5 | ........... |
| Warsaw, Ill | 1,438 | †474.00 | 0.0 | 21.4 | ........... |
| Quincy, Ill | 1,401 | 457.14 | 1.0 | 21.5 | 15 |
| Hannibal, Mo | 1,381 | 448.25 | −1.7 | 21.6 | 12 |
| Louisiana, Mo | 1,352 | 436.19 | −1.8 | 21.9 | 14 |
| Grafton, Ill | 1,276 | 212.71 | 190.0 | 215.8 | 211 |
| Alton, Ill | 1,263 | 213.17 | 189.0 | 218.6 | ........... |
| Saint Louis, Mo | 1,240 | 378.97 | 0.0 | *35.9 | 32 |
| Chester, Ill | 1,164 | †340.00 | 0.9 | 31.2 | ........... |
| Cape Girardeau, Mo | 1,107 | †301.00 | ........... | 36.4 | ........... |
| Grays Point, Mo | 1,102 | 300.06 | 0.9 | 35.0 | 31 |
| Cairo, Ill | 1,057 | 269.58 | −1.0 | 52.2 | 42 |

*In 1844 the stage reached 41.4 feet. † Elevation approximated.

*Water gauges on the Mississippi River*—Continued.

| Location. | Distance from the Gulf of Mexico. | Gauge zero above mean Gulf level. | Gauge readings. | | Bank-full stage. |
|---|---|---|---|---|---|
| | | | Lowest. | Highest. | |
| | *Miles.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Belmont, Mo | 1,039 | 265.88 | 1.4 | 45.8 | 41 |
| New Madrid, Mo | 989 | 254.54 | —0.2 | 41.5 | 34 |
| Cottonwood Point, Mo | 937 | 229.36 | —0.4 | 37.8 | 36 |
| Fulton, Tenn | 885 | 207.29 | 1.6 | 36.7 | 35 |
| Memphis, Tenn | 830 | 182.71 | —0.9 | 35.6 | 31 |
| Mhoon Landing, Miss | 784 | 160.22 | —2.2 | 40.2 | 32 |
| Helena, Ark | 754 | 140.72 | —0.2 | 48.1 | 42 |
| Sunflower, Miss | 707 | 125.82 | 2.1 | 42.9 | 36 |
| Mouth White River, Ark | 667 | 107.47 | 0.0 | 50.4 | 44 |
| Arkansas City, Ark | 622 | 95.18 | 0.3 | 50.2 | 42 |
| Greenville, Miss | 582 | 86.74 | 1.8 | 44.3 | 40 |
| Lake Providence, La | 518 | 68.36 | —3.8 | 41.9 | 36 |
| Vicksburg, Miss | 461 | 44.78 | —3.9 | 49.0 | 44 |
| Saint Joseph, La | 412 | 31.48 | —4.0 | 45.1 | 40 |
| Natchez, Miss | 372 | 15.63 | 0.0 | 48.6 | 46 |
| Red River Landing, La | 307 | 2.59 | 0.0 | 48.9 | 42 |
| Bayou Sara, La | 272 | 2.69 | —2.1 | 42.2 | 38 |
| Baton Rouge, La | 238 | —1.20 | 0.9 | 38.4 | 33 |
| Plaquemine, La | 218 | —0.20 | 0.2 | 33.8 | 28 |
| Donaldsonville, La | 186 | —2.12 | 1.7 | 30.6 | ............ |
| College Point, La | 168 | —0.02 | 0.0 | 26.0 | ............ |
| Carrollton, La | 115 | —0.35 | —1.6 | 17.4 | .12 |
| New Orleans, La | 107 | ............ | ............ | 17.9 | ............ |
| Fort Jackson, La | 33 | —1.98 | 0.5 | 6.9 | ............ |

The distances from the Gulf of Mexico, given in the above table, are channel distances above Saint Louis and mid-bank distances below that point to the Gulf. The elevations of gauge zeros are derived from duplicate lines of precise levels extending from tide water of the Gulf along the river to Saint Paul. The lowest and highest readings given are the lowest and highest stages, respectively, that have been recorded from the time the gauge was established until July 1, 1893.

Bank-full stage means that stage of water which reaches the top of the average banks in the vicinity of the gauge.

From the above table the slopes at high and low stages between successive gauges may be deduced.

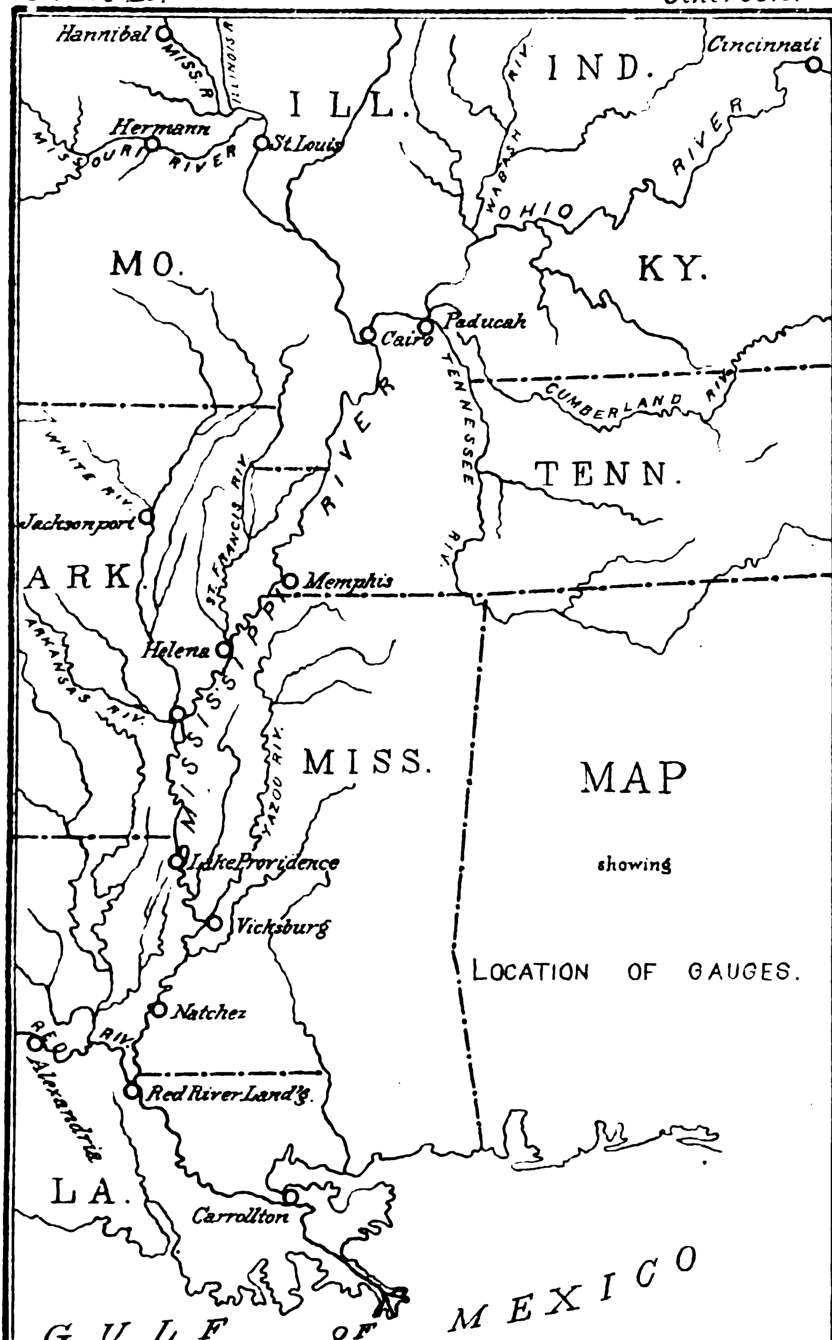
Gauges have also been established on all the principal rivers of the United States, and the river-stage bulletin of 1892, issued by the Weather Bureau, comprises daily readings at 160 stations.

The credit of developing this department of the Weather Bureau belongs to Prof. Thomas Russell, and the last bulletin bears strong evidence of his energy and good judgment.

Carefully kept and accurate continuous records of this kind will become invaluable to the future engineer who takes up the study of decrease in flow of streams. Careless records are misleading and worse than none, and it is to be hoped that the Secretary of Agriculture will see the necessity of keeping this department in the hands of a man who fully appreciates its importance, and has the skill and judgment necessary to secure and digest the desired results.

The flood planes of the river become more and more marked as we

Plate II. Ockerson.



approach the mouth of the Ohio River, and the floods grow more and more destructive as the accumulated waters of the tributaries roll down the vast alluvial plain toward the Gulf. Hence the principal data here considered is that of the Mississippi River below the mouth of the Missouri.

The table on p. 86 gives the highest stages reached at numerous points during the period 1872 to 1893. It embraces one station (Hermann) on the Missouri River and one (Paducah) on the Ohio River. The duration of the floods above bank-full stage is also given for many of the stations.

The locations of these gauges are shown on Plate II. An inspection of these locations shows plainly that the maximum stage at Saint Louis will be reached by a concurrence of high stages in the Missouri and Mississippi.

The drainage basin above Saint Louis measures about 699,000 square miles, and the total annual discharge averages 236,000 cubic feet per second, the lowest being about 45,000 cubic feet per second, and the highest, that of the flood of 1892, 1,146,000 cubic feet per second.

Plate III gives a graphical representation of the highest annual stages and the dates of their occurrence from 1872 to 1893.

The maximum stage of each year at the different stations is shown by a heavy vertical line. The length of this line shows the stage reached, the horizontal spaces representing two feet on gauge. The position of the line shows the date when the maximum stage occurred. The numbers indicate the year.

It is evident from an inspection of this plate that in that period there has been no such coincidence of floods in the Missouri and Mississippi rivers. As a rule, the floods of the Missouri come considerably later than those of the Upper Mississippi. The greatest floods at Saint Louis, during the period under consideration, occurred in 1883 and 1892. Both of these came from the Missouri. These stages were exceeded in 1844, 1851, and 1858. That of 1844 was 5 feet higher than any other well-authenticated flood. It is said that both the Upper Mississippi and the Missouri rivers were extraordinarily high at the same time. This may be considered, then, the maximum possible stage at this point.

Since that time the conditions have been very materially changed in many ways, so that the stage at the present time, which would be equivalent to the discharge at the maximum of the flood of 1844, would be difficult to estimate. The flow at the present time is restricted to a narrow channel, while in 1844 it covered the bottom from bluff to bluff a distance of several miles.

At the same time the capacity of the channel proper at high water is very largely increased by the use of present artificial embankments

that concentrate the waters and increase their scouring capacity. As this effect varies with the magnitude and duration of the flood, it is very difficult to measure. The maximum amount is reached when the scour reaches bed rock, which it did at the Merchants Bridge during the flood of 1892. This scour was more than 20 feet deep in some places, and the channel capacity was nearly or quite doubled. This, the greatest known flood near the junction of the Upper Mississippi and Missouri rivers, does not seem to have caused excessively high water in the Lower Mississippi. The maximum stage of that year at Vicksburg was several feet lower than other years, and occurred several days prior to the maximum stage at Saint Louis; hence, could not have been materially influenced by it.

Referring again to Plate II, we see that Cairo is situated at the junction of the Ohio and Mississippi rivers. The drainage basin of the Ohio and its tributaries is 207,100 square miles. The Mississippi and Missouri basins above Cairo comprise 707,300 square miles, or a total above Cairo of 914,400 square miles.

During the years 1882, 1883, and 1884 the average discharge amounted to 650,000 cubic feet per second. The river has an extreme range of 53 feet between high and low water.

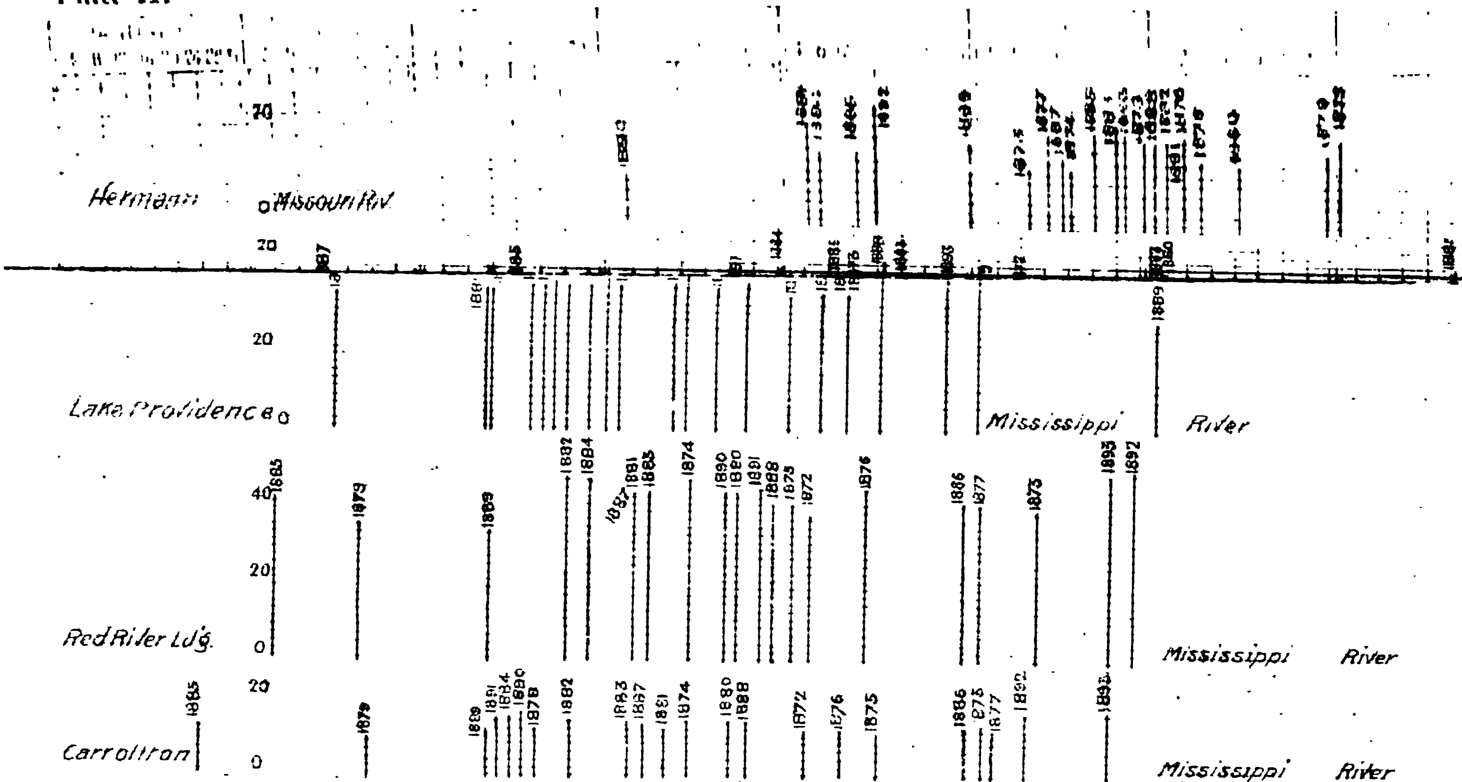
An inspection of Plate III shows beyond question where the floods of the Lower Mississippi come from. The great floods on the Ohio begin in February and have passed on down long before the floods of the Missouri and the Upper Mississippi reach the mouth of the Ohio. The only exception was in 1875, when a flood from the Missouri on August 1 was joined at Cairo by a moderate flood from the Ohio River. This caused an overflow down as far as Lake Providence. The maximum stage at the latter point occurred, however, some three months prior to the arrival of the Missouri wave.

The floods of the Missouri and Upper Mississippi rivers have never been of such volume as to become a serious menace by themselves to the Lower Mississippi Valley, and as they never come in conjunction with one another, or with the great floods of the Ohio and its chief tributaries, they have but little, if any, influence on the flood planes of the Lower Mississippi River.

Thus, the startling statement that an acre reclaimed from the arid deserts of Montana by means of reservoirs will reclaim another acre from the floods in Louisiana is seen to be wholly lacking in the essential elements of fact.

After passing the Ohio the volume of the Mississippi River at flood stages is often increased by floods from the tributaries. The White in 1892 added 181,000 cubic feet per second, the Arkansas 400,000 cubic feet per second, and the Red River 183,000 cubic feet per second. A coincidence of floods in all of these streams may occur, and the

Plate III


Hermann
Missouri Riv.
Lake Providence
Mississippi River
Red River Ldg.
Mississippi River
Carrollton
Mississippi River

high stages of the Lower Mississippi are thus augmented and prolonged.

The stages below Memphis have been modified by the renewal of the levee system, which was actively begun in 1883, and the result is that the maximum stages of the period in this reach have occurred during the last few years.

The maximum stage, where the floods are confined by levees, also depends on the number of crevasses which occur, and hence the gauge reading in itself may be rather misleading as a measure of the magnitude of the flood. In addition to the gauge readings it is important to know the discharge of the crevassees, and study their effect on stage from the first break until they reach their maximum.

Plate IV is a hydrograph of the Mississippi River, the Missouri River at Hermann, and the Ohio River at Paducah. It gives a continuous graphical record at various points for a period of twenty-one years, from 1872 to 1892, inclusive. The horizontal lines represent differences in stage of one foot. The bottom line of each hydrograph is the lowest stage reached, and the top line is the highest stage reached during the period 1872–'92. Hence, the depth of the horizontal lines gives a measure of the extreme oscillation during that period The scales at the end of each hydrograph represent the gauges as read, their zeros being sometimes above extreme low water and sometimes below.

The highest and lowest gauge readings at each station are also shown in figures. The vertical spaces represent months and years.

The full irregular line follows the oscillation in stage and represents a continuous daily record of stage at each station.

The dotted horizontal lines show the bank-full stage and its relations with the floods of each year.

*Table of highest annual stages and their dates and number of days above overflow stage during the years* 1872 *to* 1893.

| Year. | Hermann. (Missouri River.) Date. | Gauge reading. | Number of days above bank-full stage. | Hannibal. (Upper Mississippi River.) Date. | Gauge reading. | Number of days above bank-full stage. | Saint Louis. (Middle Mississippi River.) Date. | Gauge reading. | Number of days above bank-full stage. |
|---|---|---|---|---|---|---|---|---|---|
| | | *Feet.* | | | *Feet.* | | | *Feet.* | |
| 1872 | ........ | ..... | ........ | June 9 | 13.3 | 5 | June 12–14 | 23.0 | 0 |
| 1873 | June 10 | 12.6 | 0 | May 12 | 14.5 | 53 | Apr. 11 | 25.5 | 0 |
| 1874 | June 19 | 13.2 | 0 | Mar. 13 | 10.2 | 0 | June 19–20 | 18.4 | 0 |
| 1875 | Aug. 1 | 18.6 | 0 | ........ | ..... | ........ | Aug. 3 | 29.8 | 0 |
| 1876 | July 6 | 19.6 | 11 | ........ | ..... | ........ | May 10 | 32.0 | 1 |
| 1877 | June 13–14 | 19.1 | 9 | ........ | ..... | ........ | June 14 | 26.6 | 0 |
| 1878 | July 9 | 15.2 | 0 | ........ | ..... | ........ | June 15 | 25.7 | 0 |
| 1879 | June 29 | 16.2 | 0 | June 3 | 10.6 | 0 | July 3 | 21.2 | 0 |
| 1880 | July 15 | 13.4 | 0 | July 3 | 18.7 | 25 | July 12 | 25.5 | 0 |
| 1881 | May 4 | 20.4 | 8 | Oct. 27 | 20.6 | 150 | May 6 | 33.7 | 6 |
| 1882 | July 3 | 18.9 | 7 | July 2 | 18.4 | 102 | July 5–6 | 32.2 | 3 |
| 1883 | June 24 | 21.1 | 19? | May 20 | 17.6 | 68 | June 26 | 34.8 | 13 |
| 1884 | May 6 | 14.8 | 0 | Apr. 30 | 18.5 | 53 | Apr. 9–10 | 28.1 | 0 |
| 1885 | June 21 | 18.5 | 16 | Mar. 16 | 13.2 | 11 | June 17 | 27.1 | 0 |
| 1886 | May 12 | 15.2 | 0 | May 9 | 17.1 | 82 | May 13 | 27.0 | 0 |
| 1887 | June 16 | 14.4 | 0 | Feb. 13 | 12.0 | 0 | Apr. 3 | 20.7 | 0 |
| 1888 | July 1 | 16.8 | 0 | May 17 | 21.6 | 70 | June 4 | 29.3 | 0 |
| 1889 | May 30 | 16.4 | 0 | June 9 | 8.3 | 0 | June 1 | 24.6 | 0 |
| 1890 | Apr. 4 | 11.5 | 0 | July 3 | 13.5 | 12 | July 1 | 20.6 | 0 |
| 1891 | July 3 | 17.2 | 3 | Apr. 23 | 12.2 | 3 | Apr. 25 | 23.4 | 0 |
| 1892 | May 15 | 23.0 | 24 | July 3 | 20.8 | 89 | May 19 | 36.0 | 29 |
| 1893 | June 26 | 19.3 | ........ | May 27 | 16.3 | ........ | May 3 | 31.6 | 0 |
| Mean | ........ | 16.9 | ........ | ........ | 15.4 | ........ | ........ | 27.1 | ........ |

| Year. | Paducah. (Ohio River.) Date. | Gauge reading. | Number of days above bank-full stage. | Cairo. (Middle Mississippi River.) Date. | Gauge reading. | Number of days above bank-full stage. | Helena. (Lower Mississippi River.) Date. | Gauge reading. | Number of days above bank-full stage. |
|---|---|---|---|---|---|---|---|---|---|
| | | *Feet.* | | | *Feet.* | | | *Feet.* | |
| 1872 | ........ | ..... | ........ | Apr. 19 | 39.2 | 0 | Apr. 26 | 39.0 | 0 |
| 1873 | ........ | ..... | ........ | Feb. 26 | 41.5 | 0 | Mar. 6 | 40.0 | 0 |
| 1874 | ........ | ..... | ........ | Apr. 26 | 47.4 | 33 | May 11 | 45.8 | 27 |
| 1875 | Mar. 23 | 44.0 | 18 | Aug. 8 | 45.1 | 29 | Apr. 12–14 | 42.4 | 0 |
| 1876 | Feb. 5 | 44.9 | 21 | Apr. 6 | 46.4 | 33 | Apr. 18–19 | 44.8 | 33 |
| 1877 | Jan. 27 | 38.8 | 0 | Apr. 15 | 40.5 | 0 | Apr. 30 to May 1. | 41.8 | 0 |
| 1878 | Mar. 18 | 28.7 | 0 | Apr. 29 | 37.0 | 0 | May 3–4 | 38.7 | 0 |
| 1879 | Jan. 25 | 38.8 | 0 | Dec. 31 | 36.5 | 0 | Jan. 31 | 37.2 | 0 |
| 1880 | Mar. 22 | 44.0 | 21 | Mar. 22 | 44.6 | 21 | Mar. 31 | 43.7 | 32 |
| 1881 | Feb. 24 | 40.6 | 5 | Apr. 20 | 45.8 | 18 | May 14 | 43.7 | 23 |
| 1882 | Feb. 26 | 50.0 | 64 | Feb. 26 | 51.9 | 72 | Mar. 9 | 47.2 | 71 |
| 1883 | Feb. 25 | 50.7 | 22 | Feb. 27 | 52.2 | 34 | Mar. 8–9 | 46.9 | 27 |
| 1884 | Feb. 23 | 54.2 | 46 | Feb. 22–24 | 51.8 | 51 | Mar. 6 | 47.0 | 71 |
| 1885 | June 25 | 38.0 | 0 | Jan. 26 | 39.0 | 0 | Jan. 30 | 40.7 | 0 |
| 1886 | Apr. 17 | 50.4 | 18 | Apr. 19 | 51.0 | 24 | Apr. 30 | 48.1 | 24 |
| 1887 | Mar. 8 | 46.8 | 40 | Mar. 9–10 | 48.5 | 41 | Mar. 21–22 | 46.4 | 36 |
| 1888 | Apr. 5 | 40.6 | 6 | Apr. 4 | 45.4 | 0 | Apr. 14–15 | 42.8 | 5 |
| 1889 | Feb. 26 | 31.4 | 0 | June 24 | 35.4 | 0 | June 28 | 34.1 | 0 |
| 1890 | Mar. 11 | 48.5 | 42 | Mar. 12 | 48.8 | 55 | Mar. 28–30 | 47.7 | 52 |
| 1891 | Mar. 1 | 45.5 | 39 | Mar. 4–6 | 46.2 | 56 | Mar. 26–28 | 44.7 | 51 |
| 1892 | Apr. 29 | 42.9 | 10 | Apr. 28 | 48.3 | 29 | May 11–12 | 45.7 | 69 |
| 1893 | Feb. 27 | 44.3 | ........ | May 9 | 49.3 | ........ | May 25 | 48.0 | ........ |
| Mean | ........ | 43.3 | ........ | ........ | 45.1 | ........ | ........ | 43.5 | ........ |

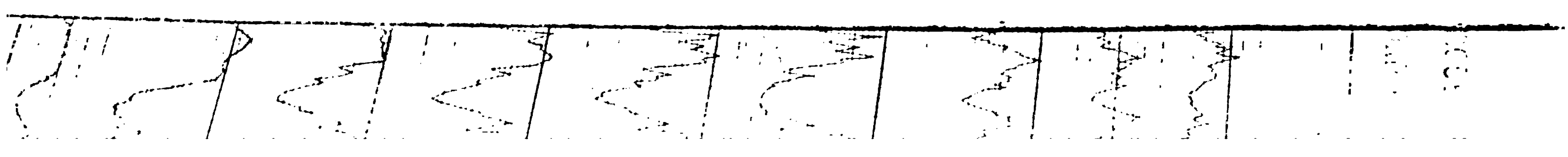
*Table of highest annual stages, etc.*—Continued.

| Year. | Lake Providence. (Lower Mississippi River.) | | | Red River Landing. (Lower Mississippi River.) | | | Carrollton, La. (Lower Mississippi River.) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Date. | Gauge reading. | Number of days above bank-full stage. | Date. | Gauge reading. | Number of days above bank-full stage. | Date. | Gauge reading. | Number of days above bank-full stage. |
| | | *Feet.* | | | *Feet.* | | | *Feet.* | |
| 1872 ..... | May 1 ...... | 35.1 | 0 | May 6 ...... | 39.4 | 0 | May 6 ...... | 12.3 | 10 |
| 1873 ..... | May 28 ..... | 36.1 | 0 | June 12..... | 39.0 | 0 | June 3-4.... | 12.9 | 71 |
| 1874 ..... | Mar. 21-23 .. | 37.4 | 74 | Apr. 16 ..... | 47.0 | 75 | Apr. 16...... | 15.7 | 90 |
| 1875 ..... | Apr. 19-20... | 37.3 | 46 | May 3 ...... | 40.4 | 0 | May 3-5, 14, 16-18. | 11.3 | 0 |
| 1876 ..... | Apr. 12-14... | 37.9 | 75 | May 15 ..... | 45.4 | 57 | May 11 ..... | 12.7 | 24 |
| 1877 ..... | May 6-7 .... | 35.8 | 0 | June 1-3.... | 40.5 | 0 | June 4-8.... | 11.1 | 0 |
| 1878 ..... | Mar. 22-24 .. | 35.8 | 0 | Mar — ..... | ...... | .......... | Mar. 21 ..... | 11.3 | 0 |
| 1879 ..... | Feb. 14-16... | 36.0 | 0 | Feb. 19-20... | 35.9 | 0 | Feb. 20-22... | 10.8 | 0 |
| 1880 ..... | Apr. 3 ...... | 38.0 | 39 | Apr. 22-24... | 44.0 | 31 | Apr. 23-24 .. | 14.2 | 80 |
| 1881 ..... | Mar. 11 ..... | 36.2 | 0 | Apr. 6-9..... | 40.1 | 0 | Apr. 12...... | 12.5 | 105 |
| 1882 ..... | Mar. 20 ..... | 38.3 | 53 | Mar. 27 ..... | 48.5 | 91 | Mar. 27 ..... | 14.9 | 190 |
| 1883 ..... | Mar. 11-14 .. | 36.5 | 0 | Apr. 9....... | 45.2 | 57 | Apr. 7....... | 15.4 | 147 |
| 1884 ..... | Mar. 23-24 .. | 38.4 | 85 | Mar. 29-31 .. | 47.3 | 97 | Mar. 18 ..... | 15.6 | 119 |
| 1885 ..... | May 10-11 .. | 35.5 | 0 | Feb. 5-6..... | 42.0 | 0 | Jan. 22-23 .. | 13.5 | 59 |
| 1886 ..... | May 7 ...... | 37.9 | 20 | May 31 ..... | 41.9 | 0 | May 31 ..... | 13.8 | 74 |
| 1887 ..... | Mar. 26 ..... | 38.0 | 28 | Apr. 8 ...... | 43.0 | 13 | Apr. 6-9 .... | 14.5 | 56 |
| 1888 ..... | Apr. 24-25... | 38.1 | 15 | Apr. 30 ..... | 41.7 | 0 | Apr. 26 ..... | 14.3 | 37 |
| 1889 ..... | July 1 ...... | 29.4 | 0 | Mar. 13-15 .. | 33.9 | 0 | Mar. 13-14 .. | 11.5 | 0 |
| 1890 ..... | Mar. 15 ..... | 41.0 | 102 | Apr. 23...... | 48.6 | 104 | Mar. 14, 15, 16, 17-22 | 16.0 | 136 |
| 1891 ..... | Mar. 31 to Apr. 4. | 41.0 | 70 | Apr. 26 to May 4. | 45.5 | 70 | Mar. 16 ..... | 16.0 | 98 |
| 1892 ..... | June 2...... | 41.9 | 83 | June 27..... | 48.9 | 92 | June 10..... | 17.3 | 118 |
| 1893 ..... | May 16-17 .. | 41.8 | .......... | June 24..... | 47.7 | .......... | June 23-25.. | 17.4 | ......... |
| Mean.... | ............... | 37.4 | .......... | ............... | ...... | .......... | ............... | ...... | .......... |

*Table of highest, and mean of high, stages and duration above bank-full stage years* 1872 *to* 1892, *inclusive.*

| Station. | Gauge zero above Gulf level. | Highest stage. | | Mean high stage, 1872 to 1893. | Bank-full stage. | Number of days above bank-full stage. | | | | | Greatest range between high and low water, 1872–1892. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Greatest. | | Least. | | | |
| | | Stage. | Date. | | | No. days. | Year. | No. days. | Years. | Mean. | |
| | *Feet.* | *Feet.* | | *Feet.* | *Feet.* | | | | | | *Feet.* |
| Hermann, Mo. River | 483.8 | 23.3 | May 15, 1892 | 16.9[5] | 17 | 24 | 1892 | 0 | 1872, '73, '74, '75, '78, '79, '80, '84, '86, '87, '88, '89, '90. | 4 | 27.5 |
| Hannibal | 448.46 | 21.58 | May 17, 1888 | 15.4[3] | 12 | 150[3] | 1881 | 0 | 1874, '79, '87, '89[3] | 43[3] | 23.33[3] |
| Saint Louis | 378.97 | 36.00 | May 19, 1892 | 27.1 | 32 | 29 | 1892 | 0 | 1872, '73, '74, '75, '77, '78, '79, '80, '84, '85, '86, '87, '88, '89, '90, '91. | 2 | 34.98 |
| Paducah, Ohio River[2] | [1] 287.16 | 54.25 | Feb. 23, 1884 | 43.3[4] | 40 | 64 | 1882 | 0 | 1877, '78, '79, '85, '89[3] | 17 | 54.00 |
| Cairo | 269.6 | 52.17 | Feb. 27, 1883 | 44.84 | 42.0 | 72 | 1882 | 0 | 1872, '73, '77, '78, '79, '85, '88, '89 | 24 | 52.07 |
| Memphis | 182.7 | 35.60 | {Mar. 23–24} {Apr. 4–5, '90} | 32.88 | 31.1 | 101 | 1882 | 0 | 1878, '79, '85, '89 | 41 | 36.55 |
| Helena | 140.7 | 48.10 | Apr. 30, 1886 | 43.27 | 42.6 | 74 | 1882 | 0 | 1872, '73, '75, '77, '78, '79, '85, '88, '89 | 25 | 48.28 |
| Mouth White River | 107.5 | 50.40 | Mar. 31, 1890 | 46.67 | 44.4 | 106 | 1890 | 0 | 1872, '73, '78, '79, '85, '89 | 34 | 50.40 |
| Lake Providence | 68.4 | 41.90 | June 2, 1892 | 37.23 | 36.5 | 102 | 1890 | 0 | 1872, '73, '77, '79, '81, '83, '85, '89 | 32 | 45.75 |
| Vicksburg | 44.8 | 49.05 | Apr. 24–25, '90 | 43.70 | 44.1 | 104 | 1890 | 0 | 1872, '73, '75, '77, '79, '80, '81, '83, '85, '89. | 24 | 52.96 |
| Natchez | 15.6 | 48.60 | Apr. 23, 1890 | 42.99 | 46.3 | 64 | 1892 | 0 | 1872, '81, '83, '85, '89 | 8 | 48.60 |
| Red River Landing | 2.6 | 48.87 | June 27, 1892 | 43.34[6] | 42.3 | 104 | 1890 | 0 | 1875, '77, '81, '85, '86, '88, '89 | 32 | 48.87 |
| Baton Rouge | 1.2 | 38.45 | June 28, 1892 | 32.47 | 33.0 | 92 | 1884 | 0 | 1872, '73, '75, '77, '79, '81, '85, '86, '88, '89. | 24 | 37.55 |
| Carrollton | —0.3 | 17.35 | June 10, 1882 | 13.72 | 12.0 | 190 | 1882 | 0 | 1875, '77, '78, '79, '89 | 67 | 18.95 |

[1] As given by United States Weather Bureau.
[2] From 1875 to 1892.
[3] Omitting the years 1875, 1876, 1877, and 1878.
[4] Omitting the years 1872, 1873, and 1874.
[5] Omitting the year 1872.
[6] Omitting the year 1878.



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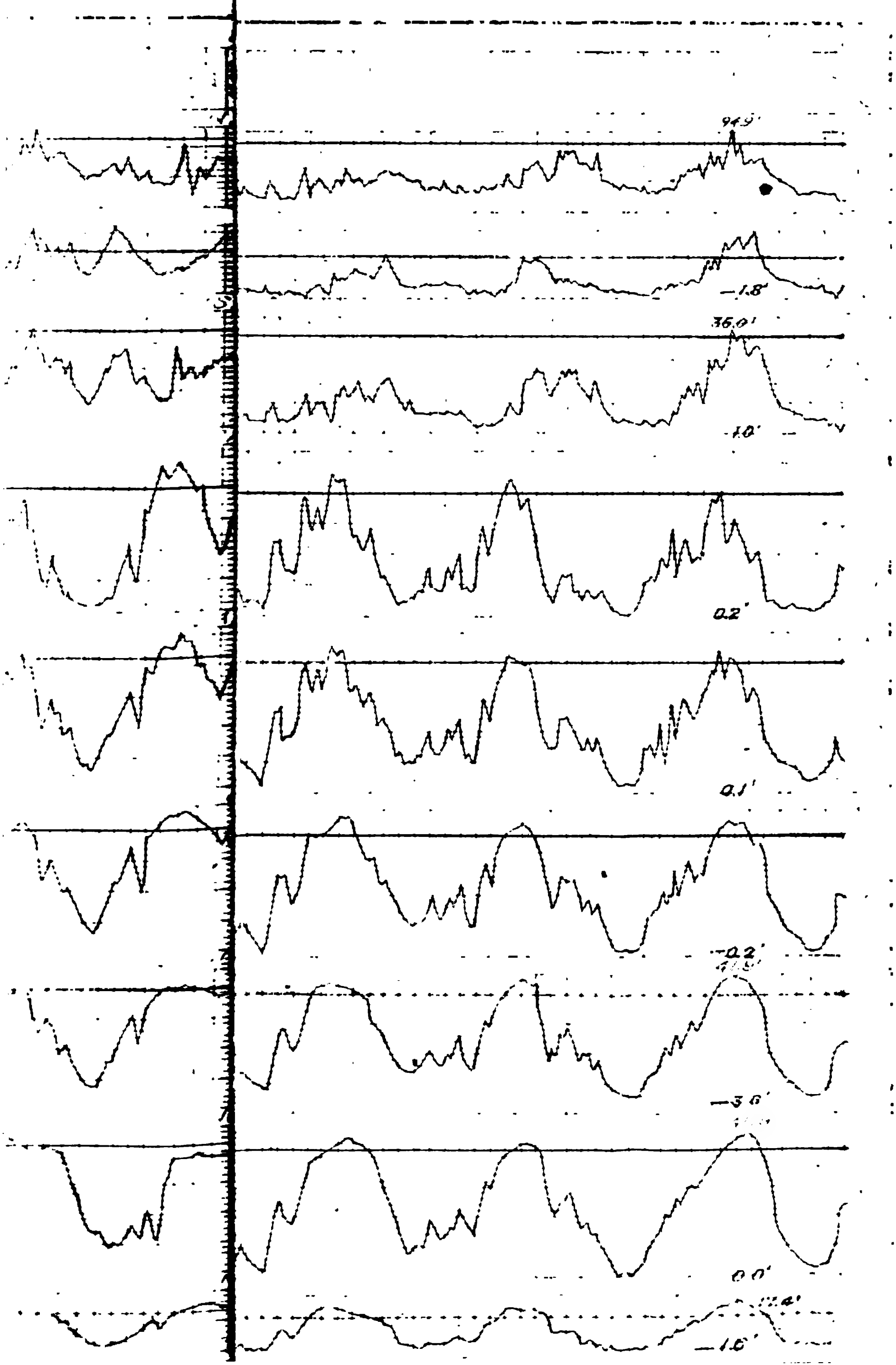

*Table of highest, and mean of high, stages and duration above bank-full stage years* 1872 *to* 1892, *inclusive.*

| Station. | Gauge zero above Gulf level. | Highest stage. | | Mean high stage, 1872 to 1893. | Bank-full stage. | Number of days above bank-full stage. | | | | | Greatest range between high and low water, 1872–1892. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Stage. | Date. | | | Greatest. | | Least. | | | |
| | | | | | | No. days. | Year. | No. days. | Years. | Mean. | |
| | *Feet.* | *Feet.* | | *Feet.* | *Feet.* | | | | | | *Feet.* |
| Hermann, Mo. River | 483.8 | 23.3 | May 15, 1892 | 16.9[5] | 17 | 24 | 1892 | 0 | 1872, '73, '74, '75, '78, '79, '80, '84, '86, '87, '88, '89, '90. | 4 | 27.5 |
| Hannibal | 448.46 | 21.58 | May 17, 1888 | 15.4[3] | 12 | 150[3] | 1881 | 0 | 1874, '79, '87, '89[3] | 43[3] | 23.33[3] |
| Saint Louis | 378.97 | 36.00 | May 19, 1892 | 27.1 | 32 | 29 | 1892 | 0 | 1872, '73, '74, '75, '77, '78, '79, '80, '84, '85, '86, '87, '88, '89, '90, '91. | 2 | 34.98 |
| Paducah, Ohio River[2] | [1] 287.16 | 54.25 | Feb. 23, 1884 | 43.3[4] | 40 | 64 | 1882 | 0 | 1877, '78, '79, '85, '89[2] | 17 | 54.00 |
| Cairo | 269.6 | 52.17 | Feb. 27, 1883 | 44.84 | 42.0 | 72 | 1882 | 0 | 1872, '73, '77, '78, '79, '85, '88, '89 | 24 | 52.07 |
| Memphis | 182.7 | 35.60 | Mar. 23–24 / Apr. 4–5, '90 | 32.88 | 31.1 | 101 | 1882 | 0 | 1878, '79, '85, '89 | 41 | 36.55 |
| Helena | 140.7 | 48.10 | Apr. 30, 1886 | 43.27 | 42.6 | 74 | 1882 | 0 | 1872, '73, '75, '77, '78, '79, '85, '88, '89 | 25 | 48.28 |
| Mouth White River | 107.5 | 50.40 | Mar. 31, 1890 | 46.67 | 44.4 | 106 | 1890 | 0 | 1872, '73, '78, '79, '85, '89 | 34 | 50.40 |
| Lake Providence | 68.4 | 41.90 | June 2, 1892 | 37.23 | 36.5 | 102 | 1890 | 0 | 1872, '73, '77, '79, '81, '83, '85, '89 | 32 | 45.75 |
| Vicksburg | 44.8 | 49.05 | Apr. 24–25, '90 | 43.70 | 44.1 | 104 | 1890 | 0 | 1872, '73, '75, '77, '79, '80, '81, '83, '85, '89. | 24 | 52.96 |
| Natches | 15.6 | 48.60 | Apr. 23, 1890 | 42.99 | 46.3 | 64 | 1892 | 0 | 1872, '81, '83, '85, '89 | 8 | 48.60 |
| Red River Landing | 2.6 | 48.87 | June 27, 1892 | 43.34[6] | 42.3 | 104 | 1890 | 0 | 1875, '77, '81, '85, '86, '88, '89 | 32 | 48.87 |
| Baton Rouge | 1.2 | 38.45 | June 28, 1892 | 32.47 | 33.0 | 92 | 1884 | 0 | 1872, '73, '75, '77, '79, '81, '85, '86, '88, '89. | 24 | 37.55 |
| Carrollton | —0.3 | 17.35 | June 10, 1882 | 13.72 | 12.0 | 190 | 1882 | 0 | 1875, '77, '78, '79, '89 | 67 | 18.95 |

[1] As given by United States Weather Bureau.
[2] From 1875 to 1892.
[3] Omitting the years 1875, 1876, 1877, and 1878.
[4] Omitting the years 1872, 1873, and 1874.
[5] Omitting the year 1872.
[6] Omitting the year 1878.

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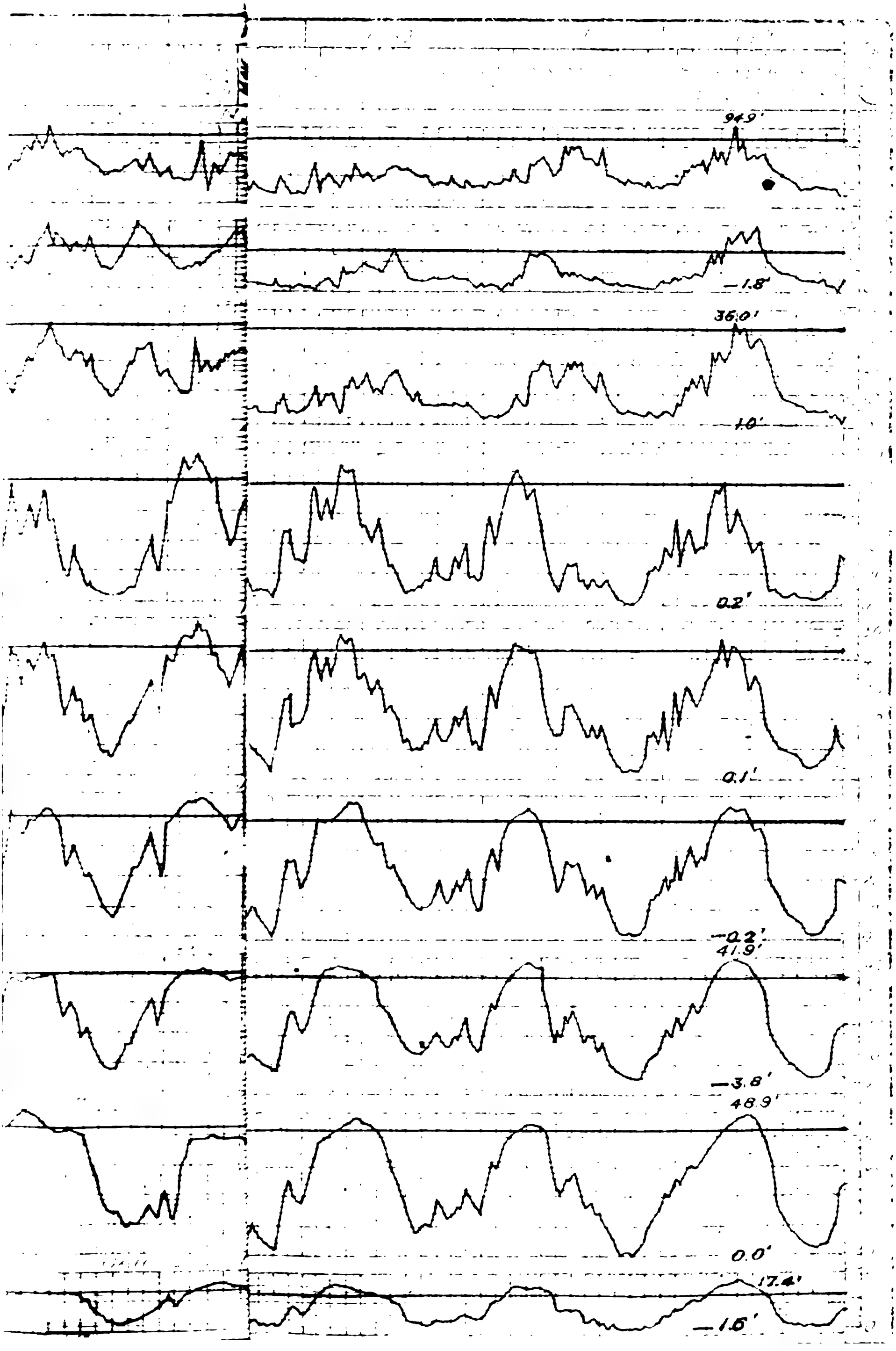

*Table of high water prior to 1872.*

| Year. | Saint Louis. | | Cairo. | | Memphis. | | Helena. | |
|---|---|---|---|---|---|---|---|---|
| | Date. | Stage. | Date. | Stage. | Date. | Stage. | Date. | Stage. |
| | | *Feet.* | | *Feet.* | | *Feet.* | | *Feet.* |
| 1815 | | | Apr. 9 | 51.6 | | | | |
| 1828 | | 36.4 | | 47.6 | | 32.7 | | 43.1 |
| 1844 | June 28 | 41.4 | | | July — | 33.0 | | 42.2 |
| 1850 | | | | | May 14 | 33.4 | May 1 | 42.8 |
| 1851 | June 10 | 36.7 | | | Mar. 11 | 33.0 | | 39.8 |
| 1858 | June 15 | 37.1 | June 21 | 49.6 | June 23 | 34.0 | July 2 | 44.6 |
| 1859 | | | May 7 | 46.5 | May 12 | 33.9 | Mar. 22 | 43.6 |
| 1862 | Apr. 26 | 31.4 | May 2 | 50.8 | | | | 46.4 |
| 1867 | May 1 | 28.2 | Mar. 21 | 51.0 | Mar. 26 | 33.9 | | 45.8 |
| 1868 | May 14 | 24.2 | May 19 | 45.6 | | | | |
| 1869 | July 24 | 29.3 | | | | | | |
| 1870 | Apr. 16 | 26.2 | | | | | | |
| 1871 | Mar. 17 | 21.8 | | | | | | |

| Year. | Vicksburg. | | Natchez. | | Baton Rouge. | | Carrollton. | |
|---|---|---|---|---|---|---|---|---|
| | Date. | Stage. | Date. | Stage. | Date. | Stage. | Date. | Stage. |
| | | *Feet.* | | *Feet.* | | *Feet.* | | *Feet.* |
| 1809 | | | May 4 | 46.9 | | | | |
| 1811 | | | June 4 | 47.0 | | | | |
| 1813 | | | June 8 | 48.2 | | | | |
| 1815 | | | June 22 | 49.2 | | | | |
| 1823 | | | May 23 | 48.3 | | | | |
| 1824 | | | May 6 | 47.8 | | | | |
| 1828 | | 46.3 | Mar. 26 | 48.8 | | 34.7 | Apr. 1 | 15.2 |
| 1844 | June 26 | 46.1 | July 16 | 47.9 | | 33.9 | | 14.5 |
| 1850 | June 4 | 47.0 | | 47.3 | Mar. 15 | 34.5 | Jan. 21 | 13.8 |
| 1851 | | | Apr. 3 | 47.1 | Apr. 1 | 34.5 | Mar. 27 | 15.4 |
| 1858 | June 26 | 46.9 | June 28 | 47.8 | | 34.5 | May 10 | 15.1 |
| 1859 | Apr. 21 | 48.2 | May 2 | 49.0 | May 6 | 35.0 | May 4 | 15.6 |
| 1862 | Apr. 27 | 51.1 | | 49.9 | | 36.1 | | 15.9 |
| 1867 | | 49.0 | | 47.9 | | | | |
| 1868 | | | | 43.9 | | | | |
| 1869 | | | | 46.1 | | 34.5 | | |
| 1870 | | | | 44.3 | | | | |
| 1871 | | | | 43.8 | | 34.5 | | 15.4 |

## 3.—RIVER STAGE PREDICTIONS IN THE UNITED STATES.

THOMAS RUSSELL.

The river service of the United States Weather Bureau has 191 river gauges, mostly at large cities on the principal rivers throughout the country. A record is kept of the daily stages of the water in the interest of low water navigation and for flood warnings. Besides the Weather Bureau gauges others are maintained along the Mississippi and Missouri rivers by the Mississippi and Missouri River Commissions in the interest of river improvements that are being made.

A river gauge consists of a plank about a foot wide and of sufficient length to include the range of water from low to high water, and is marked to feet and tenths of a foot. It is fastened to a bridge pier, where one is available, or it may consist of a narrow strip of a stone pier dressed down to a smooth surface to receive the marking and numbering. Where there is no bridge pier available, a gauge is made

of heavy timbers, 6 by 12 inches, laid along the incline of a river bank, with a strip of iron fastened along the top for the marking. A gauge is placed with the zero of graduation at the level of the lowest water as near as possible. The marks indicate vertical heights of the water surface above low water. The gauge readings are called stages. The stages read daily at 8 a. m. are telegraphed to various places interested in information as to the stages of rivers. At a number of the larger cities throughout the country a river bulletin, in connection with the weather maps, is issued daily from the Weather Bureau offices.

At high water when there is danger of a river overflowing its banks the observations of stages are of interest to districts liable to be flooded. To places where definite information of the extent of a coming high water can be given warnings are sent by telegraph.

The highest water in a freshest, or the crest stage, occurs first toward the head waters of a river. After a flood wave forms there is a progressive motion of the crest down stream at the rate of three or four miles per hour. This renders it possible to form some idea of what the highest stages of water will be along the lower course of a river from the stages along the upper course. Better predictions of high stages can be made the greater the length of record on which to base a rule for prediction. Accurate predictions of river stages at low water are not possible. Where the discharges of a river for low stages are known, that is, the quantity of water passing through the river for different stages near low water, estimates can be made ahead of stages below which the river will not fall; but the least fall of rain after the prediction is made makes the river rise at low stages very rapidly.

At high water predictions of stages are made in various ways, depending on the nature of the rivers.

In the case of two places on the same stream, the gauge readings are more or less closely dependent, according as the distance between them is less or greater. The gauge readings follow each other more closely in a rise the less the quantity of water coming into the river from the drainage area between them. Predictions of the lower stage from the upper one can be made more accurately the less the proportion of the drainage area between the two places bears to the whole drainage area above the lower place.

The character of a river varies greatly along its water course as to slope and width. Though two places on the same stream, a hundred miles or so apart, may have nearly the same quantity of water passing them, the stage at one of them may be twice as high as at the other, the difference being made up by the greater width of the river or the greater velocity of the water at the one as compared with that of the other. At Louisville, for instance, on the Ohio River, 132

miles below Cincinnati, the drainage area above it is 84,600 square miles. The drainage area above Cincinnati is 71,300 square miles. The record of stages shows that the highest water at Louisville occurs about one day after the highest water at Cincinnati. By taking the means of groups of crest stages at Cincinnati for stages about five feet apart, and the means of subsequently occurring crest stages at Louisville, the following corresponding stages, in feet, for the two places are obtained:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Cincinnati | 40 | 45 | 50 | 55 | 60 | 65 | 70 |
| Louisville | 17 | 20 | 26 | 32 | 38 | 43 | 46 |

This table is used for predicting the stage crest at Louisville when the highest water at Cincinnati is known, or when it can be estimated closely from previously occurring high stages at points above it.

For a place where a rise in the river is the result of rises in comparatively large tributary rivers, the best method of deriving a rule for stage prediction is by the comparison of the rises at the place with the preceding rises at places on the streams above it. The principle on which a rule for prediction is derived in such a case is as follows, in the case of Cairo, Ill., for example: At Cairo, Ill., near the mouth of the Ohio River, a rise may be the result of a rise at any or all of the following places: at Saint Louis, on the Mississippi River, 168 miles above the mouth of the Ohio River; at Mount Carmel, Ill., on the Wabash River, 178 miles above Cairo; at Evansville, Ind., on the Ohio River, 183 miles above Cairo; at Nashville, Tenn., on the Cumberland River, 215 miles above Cairo; at Johnsonville, Tenn., on the Tennessee River, 140 miles above Cairo.

The drainage area above Saint Louis is 699,000 square miles. The quantity of water passing in the river at the lowest stage is 48,000 cubic feet a second; at the highest stage, which is 36 feet, 1,146,000 cubic feet a second. Above Mount Carmel the drainage area is 26,000 square miles, the discharge at the lowest stage 14,000 cubic feet a second, and at the highest, 28 feet, 220,000 cubic feet. Above Evansville the drainage area is 99,700 square miles, the low water discharge is 60,000 cubic feet a second, and at the highest stage, 49 feet, about 660,000 cubic feet a second.

The drainage area above Nashville is 11,600 square miles, the low water discharge is 7,000 cubic feet a second, and at the highest stage, 58 feet, 160,000 cubic feet per second.

Above Johnsonville the drainage area is 36,700 square miles, the low water discharge is 33,000 cubic feet a second, and at the highest, 48 feet, about 450,000 cubic feet.

At Belmont, Mo., on the Mississippi River, 20 miles below Cairo, the low water discharge is 176,000 cubic feet a second, and the high water discharge, corresponding to a 52-foot stage at Cairo, is about 1,603,000 cubic feet.

A rise at one of the up-river stations has more effect in producing a subsequent rise at Cairo the greater the length of time the higher stage lasts at the up-river station. The continuation of the higher stage beyond three days has no effect in increasing the rise at Cairo For a less continuation than three days, the rise at Cairo is a proportional part of the greatest rise that takes place for a three-day continuation of the high stage.

From a consideration of the slopes of the river-surfaces between Cairo and the up-river stations for different stages at the various places from low to high water, and the varying cross-sections and depths for the different stages at the various places, the ratio of a one-foot rise at the various places to the corresponding rises at Cairo is derived theoretically, as far as the data will permit, taking into account the extent of cross-section and the velocity of water as affected by different depths and slopes.

A comparison of the theoretical rises thus obtained with the rises actually observed in cases for which there are records, gives a factor for each place for certain stages. Only a few of the possible cases that can occur have ever been observed.

The record of stages at Cairo and the up-river stations is too short, as yet, to furnish cases of all the possible variety of combination of freshet wave crests from the various rivers which produce a high water at Cairo. For the possible cases which may occur in the future, but of which there are no observations as yet, the theoretical value of the rise found as described is multiplied by a factor derived for the stages at which there have been actual observations of rise. In this way tables are prepared which show the relation of a one-foot rise at the various places to the subsequent rise in three or four days at Cairo, that being the crest-wave time between Cairo and the various places. The rise at Cairo is taken as the sum of the various computed rises at the five places.

In case of a fall at any of the places instead of a rise, it enters the sum with a minus sign.

The stage that will prevail at Cairo can be estimated six to seven days ahead from the stages at Cincinnati, Chattanooga, and Saint Louis, with allowance for the water coming out of the Cumberland and Wabash. But as the cross-sections at Cincinnati and Chattanooga are not known, the rule for prediction of stages has to be based on the comparison of actually observed rises.

In cases where the discharges and cross-sections of rivers at places are not known, some idea can still be formed of the relative importance of different tributaries in causing a rise at a point on a main stream, provided there is a long record of stages with rises at the lower point due to rises, sometimes in one of the tributaries and

sometimes in another. This permits of estimating the effect of each separately.

A rise at a high stage of a river has more effect than an equal rise at a low stage in producing a rise at a point lower down the river. On the other hand, the higher the stage at the lower point the less the effect of a rise at an up-river point in producing a rise below.

The products of the rises by the mean stages during the rises are taken as comparable throughout the range of stages at the place. For very high stages this does not hold good. Where a river overflows its banks and becomes miles in width, very great rises at up-river stations have very little effect in producing a further rise below, and it is impossible to estimate effects in such cases.

In some cases the extent of the drainage areas above up-river gauge stations is taken into account in devising a rule for predicting a high-water stage at a lower point. In a case of this kind at Pittsburg, the prediction is based on the stages at the following places above it:

| | *Sq. miles.* |
|---|---|
| Oil City | 4,526 |
| Brookville | 400 |
| Confluence | 782 |
| Rowlesburg | 886 |
| Weston | 140 |
| Johnstown | 711 |

The effect of a rise at a place in producing a rise at Pittsburg is taken as proportional to the square root of the area above it. The whole area above Pittsburg is 17,000 square miles. The areas above the six places comprise 7,445 square miles of the area above Pittsburg. The rise at Pittsburg multiplied by the mean stage during the rise, and by an unknown factor for a number of selected cases of great rise, are placed equal to the sums of the rises at the six places above, weighted according to the square root of the drainage areas above them, the unit of area being taken as 1,000 square miles. From these the value of the unknown factor is derived. With the factor a table is prepared which gives the highest stage at Pittsburg when the rises at the upper gauge are known.

Gauge readings at a place made on successive days, or at intervals a few hours apart, during a rise are of some service as indicating how high the water may be expected to go. The characteristic of a rise for most places is that the rate of rise, small at first, gradually increases as the rise continues, until a maximum rate is attained, and then diminishes until it becomes zero at the crest stage. The characteristic variations in rate of rise vary greatly in different places, depending largely on the slopes of the ground over the drainage area and on the customary distribution of rainfall. As a rule, the characteristics of a rise are more permanent or more nearly alike in

different rises the greater the drainage area above a place. At Cincinnati, for example, on the Ohio River, the rate of rise begins to diminish on the average about three days before the crest stage is reached. This is, therefore, a useful criterion in judging how long the river will continue to rise. The observed rate of rise can be used to estimate a stage for some time ahead. This is, however, mostly an uncertain method, and only to be used where other methods are not available.

In some cases, where there is only a single gauge on a river and the drainage area above it is small, the reliance in making predictions must be wholly on observations of the depth of rainfall over the area. Definite stage predictions are out of the question in such cases, and the most that can be said is that a very high stage will prevail when the rainfall over the area is seen to exceed a certain amount for the average of a number of stations.

As an example of this it requires, at the least, a rainfall of 3 inches in less than three days over the 15,000 square miles of drainage area of the Potomac River to raise the stage at Harpers Ferry to 34 feet, which corresponds to 12 feet at Washington, D. C., twelve hours later.

Over the Savannah River drainage area of 7,500 square miles it requires a rainfall of 5 inches in three days to cause the river to rise at Augusta, Ga., to the highest stage known, which is 38.7 feet.

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## 4.—METHODS IN USE IN FRANCE IN FORECASTING FLOODS.

M. Babinet.

*Historical.*—In requesting M. Georges Lemoine, *Ingenieur en chef des Ponts et Chaussées*, Paris, to present a paper on the methods in use in France in forecasting floods, for the International Congress of Meteorology to meet at Chicago in August, 1893, the Honorable Chairman of the Section devoted to Rivers and Floods kindly remarks that the idea of predicting the level of rivers originated in France, and that questions of this nature have been treated there with more care than elsewhere.

It was in 1854 that the illustrious Belgrand organized a network of permanent hydrometric observations in the basin of the Seine. He derived, a short time after, a preliminary rule for the forecasting of floods at Paris; about the same time similar investigations yielded appreciable results on other French rivers better naturally disposed, without doubt, to facilitate the forecasts. M. Camoy tried to predict the floods of the Loire at Orleans and Tours from observations made at points above and below as far as the confluence of the Allier, below which the Loire receives no important affluent throughout 300 kilometers of its length. M. Poincaré did the same for the Meuse, the

situation of which is similar, from the place where it leaves the Department of the Vosges to its entrance into the Ardennes.

The relation of cause and effect which attaches to the swelling of certain rivers in the principal stream of which they are tributaries must have previously attracted the attention of some bright minds. It was known that heavy rains, especially in mountainous regions, could, by their accumulation and the simultaneousness of their progressive flow through the plains, produce inundations at points lower down.

But the possibility of analyzing in every case these complex phenomena and extracting from them information of practical value had not been demonstrated before the investigations of Belgrand. His fundamental work (*La Seine, régime de la pluie, des sources, des eaux courantes*, Paris, chez Dunod, 1873) laid the foundation of a new science, hydrology, of which the forecasting of floods is but an interesting application.

The affluents of the Seine coming from permeable soil (oölite, chalk, limestone), rise more slowly than the others. Their slopes are almost always more feeble; except in certain exceptional circumstances, the absorption of water by the ground is greater; the superficial flow at the start is a matter of very great importance.

These considerations, in connection with very complete geological investigations, have, in predicting the maximum of a flood at Paris, permitted of neglecting the movement of the upper part of the river above the confluence of the Yonne, in spite of the extent of the basin, and that of the Aube in the Jurassic and Cretaceous formations. The Yonne, the Marne, and their principal affluents, are all that it is necessary to take into account.

*The time of propagation of the wave crest.*—The rapidity of the flow of water on the surface of impermeable ground does not permit of making forecasts in time to be of use unless the observations that serve as a basis are made at a great distance above. Even as far below as Paris, where the Seine, full formed, is far from having a torrential régime, the interval of a wave crest at two stations, with no important lateral valley intervening, corresponds frequently to a velocity of four kilometers an hour, if not more.

In 1854 telegraphic communication was not so perfected as to-day. A whole day could easily be lost before advices could be received from the most interesting stations.

This was the reason why the principal points of observation were chosen by Belgrand toward the limits of the higher upper impermeable lands, as indicated in the *Manual Hydrologique du Bassin de la Seine* (Imprimerie Nationale, 1884, p. 50).

*Prediction of floods by rises.*—It happens frequently that several oscillations close together in a water course in the upper part of the

region in question correspond to a single continuous great rise of the Seine in the vicinity of Paris; it is a multiple wave of which the maximum does not depend alone on the highest stages prevailing at the points above. The successive waves unite below, where their velocity slackens, and where there is thus a very great accumulation of water. From this has arisen the practice, for the basin of the Seine, of considering the relation of rises of which the name alone is scarcely a definition. Even in the case of simple waves, produced by a single group of rains, the rise (or the difference between the level of the water at the beginning of the rise and when the highest point is reached) has the advantage of being independent of the stage whence it starts, if it is not artificially influenced by a movable dam which is finally lowered.

Certain rises may, moreover, be taken as representative signs or evidences of the hydrological phenomena of which a neighboring region is the theater. It is in this way that in the rule for announcing floods in the Seine at Paris Belgrand was able to make use of the Aisne at Ste. Menehould and the Aire at Vraincourt, even though the waters of these two rivers run into the Oise and have not, consequently, any actual influence on the stage as read from the gauge on the Austerlitz bridge. For a similar reason, in order to take into account the great superficial extent of the basin of the Marne, in place of double the rise taken at a single point of the river conveniently chosen, the formula for prediction at Paris contains the rise of the Marne at Chaumont and St. Dizier, one of which precedes the other except for the changes due to the intermediate tributaries.

Whatever may be thought of the principle of this method, it is in any case justifiable by the excellence of the results; for the three great floods at Paris have been predicted one or two days in advance within a few centimeters of the correct stage, notably those of March, 1876, and February, 1889. The same processes have been employed elsewhere by M. G. Lemoine in predicting the floods of the principal tributaries of the Seine, as may be seen in the *Manual Hydrologique* mentioned above (pp. 51–55).

The prediction of floods by rise is moreover well adapted for taking into account certain necessary corrections due to accessory influences; it is susceptible of improvement. As, for instance, when at a station for which predictions are made a flood occurs when the stage is falling, that is to say, for a sufficient length of time before the river has returned to the normal level of the season, the rise calculated by the ordinary formula ought generally to be reduced in a certain proportion; a part of the water is used in a manner to overcome the tendency toward lowering, or is absorbed by the drawing effect of the preceding movement.

The rise to be predicted at a lower station may moreover be a dis-

continuous function of those at points above; it is therefore highly probable that when the river rises above the level at which in a number of places the wetted perimeter of a cross-section increases sharply for a slight increase of height (flood levels) these anomalies are less appreciable than at principal stations, where the phenomena occurring in a great basin proceed more regularly; for reasons of the same nature they are less to be feared than more important floods. If the announcement of slight changes is of any interest on second-class rivers, floods may be classified by families according to the initial stages or the magnitudes of the rises and a special formula may be used for each kind. This has been tried recently for some stations in the basin of the Oise.

*Announcement of floods by absolute stages.*—The study of stages, very extensive in the basin of the Seine, of which the hydrologic complication is sufficiently great, is not so generally in use on the other French rivers where the situation is different.

On the Seine itself where, on the tributaries, without giving up the method of predicting by rises which generally permit of making predictions a sufficient length of time ahead, it has been possible in the last fifteen or twenty years, especially, to utilize the extension of the telegraph for obtaining in time information as to the stages occurring successively at upper stations so as to make them of use for predictions at places lower down, as Paris or Mantes, and to draw from them conclusions useful for points along the lower course of the river. Inspector General Allard, former President of the Commission on the Forecasting of Floods in the Ministry of Public Works, has given, in a special work, a certain number of secondary rules determined in this manner (*Annales des Ponts et Chaussées*, 1889, 1er sem., vol. XVII, pp. 689 and following).

When a sufficiently great distance separates two stations between which the course of the water considered does not receive any important tributary, or if the velocity of propagation of floods between these two points is small, the prediction can be made by the aid of a graphical process in which (1) the abscissas are the maximum stages occurring at the upper station in a certain number of previous floods, (2) the ordinates are the maxima corresponding to the lower station. The extremities of the ordinates give generally a regular curve which permits of finding the highest stage to be predicted from the corresponding abscissa, the stage at the upper station.

An analogous graphic method was proposed in 1882 by M. Lavoinne, in a more complicated case, to study the relations between the maxima of the Seine at Rouen, that of the Seine at Mantes, and the level of the sea at Havre about thirty-six hours in advance. The stage at Havre was taken as abscissa and that at Mantes as ordinate, and alongside of the point thus located was written the stage that resulted at

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Rouen. If there was a constant relation between these three variables, all the points of equal stage ought to be on a regular curve, the projection of a line of level on a surface conceived to give in space the relation in question. This proceeding, devised anew by M. Mazoyer for the prediction of floods of the Loire in the vicinity of Nevers (*Annales des Ponts and Chaussées*, 1890, 2d sem., vol. xx, pp. 451 to 511), is modified somewhat: one of the variables is not always the height of water actually observed on a gauge at an upper station, but the mean of the maximum stages indicated by the observations of a certain number of tributaries whose relative influence can be taken into account by the aid of proper coefficients.

In the two cases in question, the graphical processes can be replaced by tables of single or double entry, as has been done by M. Jollois for the upper Loire. (*Annales des Ponts et Chaussées*, 1881, 1er sem., vol. I, pp. 273 to 322.)

It seems useless to dwell here on the investigation of formulas and unknown coefficients (by trial or by the method of least squares), *in fine*, on the graphic representation of the relation found in numbers by means of the processes indicated in the *Nomographie* of M. d'Ocagne (Gauthier Villars, 1892, pp. 65 to 81). This latter method, in particular, is not yet completely studied, and its practical application in hydrometry can not be pronounced upon immediately. In these investigations the important point is to be satisfied as to the conditions indicated for great floods; it is rarely that the others have an equal interest for dwellers along rivers.

*Prediction of floods from rains.*—At the present time it is possible to speak affirmatively as to the possibility of effectively using observations of rainfall for predicting the level of the water in the rivers of certain regions; they have served as the basis for hydrological studies but do not appear to be easily usable. (*Manual Hydrologique du Bassin de la Seine, p.* 50.)

In very impermeable basins with small extent of surface and high slopes the details of observations of rainfall permit of appreciating more readily than elsewhere the probable circumstances of water flow. It is precisely in regions of this kind that it is especially difficult to procure in time observations of the heights of small rivers along the upper courses, which permit of eliminating the influence of the nature and configuration of the ground, its dryness, its temperature, or other perturbing action.

In studying the floods of a very little river in the north of France (the Liane) which empties in the straits of Calais at Boulogne-sur-Mer, M. Voisin has shown that, in certain cases at least, having regard to these influences, one can, without passing through the intermediary of river gauges at upper stations, give approximate estimates of stages in time to be of use. (*Annales des Ponts et Chaussées*, 1888,

1er sem., vol. XV, pp. 464 to 510.) He has obtained since that time certain satisfactory results. Some analogous propositions which have not as yet, however, been sanctioned by any practical results, have been made by M. Tinbeaux for the Durance. (*Annales des Ponts et Chaussées*, 1892, 1er sem., vol. III, pp. 166 to 196.) Divers studies of the same kind appear to have been pursued by the hydrometric services recently organized in conformity with the advice of the Commission on the Prediction of Floods, at the instance of M. G. Lemoine for the Ardèche, the Herault, and other rivers which descend rapidly from the Cevennes to the Rhône or Mediterranean. It is beyond doubt very difficult to make numerical forecasts in the greater number of cases, but it is nevertheless a good deal to be able to announce in such regions a few hours in advance the approach of an important or dangerous flood. Only two points so far seem to be established for the small drainage area of the Liane: (1) the possibility of estimating the degree of saturation of the soil in a certain zone from the height of water on a gauge at a greater or less distance from a down-river station, notably at the very place from which the predictions are issued; (2) the influence of the hourly rate of rainfall. It is not immaterial from the point of view of the flow of water that a certain depth of rain had been caught in the rain gauges in a very short time or in a great many hours; in this latter case it has a much greater chance of being absorbed by the ground or being in great part evaporated.

*Registering apparatus.*—All the information necessary can be obtained by visual observations distributed at intervals sufficient for the purpose for which they are desired. The rapidity of the phenomena, however, is at times so great, especially in mountainous regions, that it is sometimes well to have, in addition to river gauges and the ordinary rain gauges, apparatus adapted (1) to signal, by electricity, the instant of time when the quantities to be observed reach certain important values, (2) to register the details of their variations.

Different French makers of instruments of precision (notably Messrs. Richard, Parenthon, and Chateau) make self-registering river and rain gauges of which the indications are of great value. The use of this kind of apparatus is gradually becoming greater; they would be used to a much greater extent were it not for the obstacles of the very high price and the cost of their maintenance. For a stream as torrential as the Durance it is almost indispensable to have self-registering apparatus at one station at least at the head waters.

*Prediction of floods by discharges.*—In order to satisfy the desire expressed by the Chairman of the Section devoted to Rivers and Floods of the Meteorological Congress, a few words must be said regarding the use of discharge observations in predicting the level of rivers. This method is not in current use in France where the gaugings of

water courses have only been made at a small number of places and have no relation to each other and are, in general, only slightly comparable. To extract anything from data of this kind, one is especially embarrassed by the manœuvering of movable dams on the numerous rivers where navigation has been improved by artificial means. Finally, there does not exist on any French water course anything that can be compared to the great work done for the Elbe and its tributaries in Bohemia under the direction of Prof. Harlacher of the Polytechnic Institute at Prague. It was only after eighteen years of patient investigation that he succeeded, in 1881, in perfecting his method of prediction by discharges, published over his signature and that of Prof. Richter in the month of December, 1886 (*Zeitschrift für Bauwesen*, 1887). There is often difficulty in choosing two or three stations along head waters, such that the sum of their discharges, increased in a certain proportion to take into account the additions from secondary streams below, produce with sufficient exactness the discharge in a determinate time at the station for which the predictions are to be made. If this correspondence is attained, might not one find an approximate relation by a simpler application of the absolute stages or the rises, without passing through the intermediary of the gaugings? To obtain the greatest chances of success, the discharges ought to be well determined in connection with the observation of levels at upper points; there ought to be a great variation of height without any notable change of volume in the water passing per second; this supposes that the valleys are embanked. At the same time an appreciable error in the discharge ought not to involve at the lower station any great uncertainty in the corresponding height of water; this case is presented only in a flat valley with a large, broad bed. These conditions are not found together in France, where the water courses have for the most part a régimen too variable to permit of the method in question being applied advantageously.

### GENERAL ORGANIZATION FOR THE PREDICTION OF FLOODS IN FRANCE.

*Conclusion.*—In what precedes there has been no question as to the dissemination of warnings, for transmission is not directly bound up with the technical work of prediction. Scientific progress cannot be obtained by decree, admitting that in many other cases it is possibly realizable.

The important results obtained by Belgrand for the basin of the Seine preceded all corresponding administrative organization. Yet the investigations to which local services ought to devote their energies in order to make useful predictions are often long and difficult. The persons charged with them give them special attention when they expect to find a way to derive satisfactory rules through skillful combinations, and when the labor and ingenuity bestowed in such studies

do not risk passing unnoticed. The Commission on Prediction of Floods, instituted in 1875 under the Ministry of Public Works at Paris, has certainly played from this point of view a very important rôle. It has organized in a permanent, definite manner the service of observation, the preparation of warnings, and their distribution throughout almost the whole of France. The results obtained in France up to the present time have been attained without very great expense, and without the powerful means which have recently permitted the *Central Bureau für Meteorologie und Hydrographie* of the Grand Duchy of Baden to produce the recent magnificent publication on the Rhine and its affluents. With more modest resources, the hydrometric services of the different French basins have probably not yet said the last word.

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## 5—THE FOUR GREAT RIVERS OF SIBERIA.

FRANZ OTTO SPERK.

The whole northern portion of Asia that bears the name of Siberia, extending from the Ural Mountains in the west to the waters of the Pacific Ocean in the east, *i. e.*, approximately from the fiftieth to the one hundred and fortieth meridians east of Greenwich, covers (according to the computation of Mr. Strelbitsky) an area of 231,637* square miles, or 12,757,864 square kilometers, not including the islands. This vast territory is intersected by four enormous river basins. Three of these rivers, the Obi, the Yenisei, and the Lena, receive their waters from the Altai and Saian mountains and their numerous spurs, and empty into the Arctic Ocean; while the fourth, the great Amoor River, discharges its waters into the Gulf of Tartary of the Pacific Ocean. I shall not speak of the rivers of the extreme north of Siberia, such as the Piasina, Khatanga, Olenek, Yana, Indighirka, Kolyma, Anadeer, and others, although some of these are very large.

The dimensions of the four principal river systems of Siberia are as follows: (1) The river Obi has a length of 701.5 miles, or 5,206 kilometers; its basin comprises an area of 54,118 square miles, or 2,980,646 square kilometers. (2) The river Yenisei, with the Angara, Lake Baikal, and the Upper Angara River, has a length of 540.5 miles, or 4,011 kilometers; the basin extends over an area of 37,257 square miles, or 2,051,996 square kilometers. If, however, the Selenga River is taken as the beginning of the Angara, both the length and the area of the basin would be considerably increased. (3) The Lena has a length of 619.7 miles, or 4,599 kilometers; the area of its basin is 42,743 square miles, or 2,354,203

*The Prussian mile seems to be used throughout this paper. The English equivalent is 4.66 statute miles. The temperatures given are in centigrade degrees.—EDITOR.

square kilometers. Finally, (4) the Amoor River is 603 miles, or 4,478 kilometers, long; and the portion of its basin belonging to the Russian Empire covers an area of 18,300 square miles, or 1,007,901 square kilometers.

There can be no doubt as to the great importance of these rivers for the climate of the country. Thus the annual covering of these rivers with ice and their delivery from the ice must exert a powerful influence on the temperature of the locality, for the formation of the ice absorbs a large amount of heat, and the cover of ice over the rivers changes the conditions of evaporation and radiation; again, the thawing of the ice appreciably lowers the air temperature of the spring months. Thus, while the rivers are, so to speak, a product of the climate of the country, they may themselves serve, apart from direct meteorological observations, as an indication of the greater or less amount of precipitation, and their changes of level may allow inferences as to the annual distribution of the precipitation. The existence of the mighty rivers of Siberia, with their numerous powerful and extensive tributaries, shows clearly that Siberia is not deficient in precipitation; and the considerable changes of level taking place in these innumerable rivers *at different times* indicate that this rather large amount of precipitation is not uniformly distributed over the various parts of Siberia and through the seasons. In general, precipitation is greater in the west in summer, in the east in winter. Unfortunately, the questions that meteorology might raise concerning the Siberian rivers have, as yet, hardly been seriously considered. Besides the work of Dr. Rykatschew "On the Opening and Freezing of Rivers," and that of Dr. Stelling "On the Discharge of Water of the Angara," some scanty material, not yet scientifically elaborated, is to be found in various works concerning the discharge of rivers and allied problems.

The present brief sketch is based on all the material I have been able to collect, and on my personal observations and recollections from an eighteen years' residence in Siberia.

I shall begin with the freezing and opening of the rivers, these phenomena accompanying the transition from summer to winter, and again from the cold to the warm season. While the times of the freezing and opening of the rivers vary within rather wide limits, these limits are more narrow in Siberia than in European Russia. I give below a table derived from the results of Dr. Rykatschew, and exhibiting the mean and maximum deviations from the general means for the separate periods:

*Table showing mean and maximum deviations.*

| | For a 20-year period. | | | | | |
|---|---|---|---|---|---|---|
| | Opening. | | Freezing. | | Free from ice. | |
| | Mean. | Maximum. | Mean. | Maximum. | Mean. | Maximum. |
| | ° | ° | ° | ° | ° | ° |
| River Obi at Barnaul | ± 1.1 | − 3 | ± 2.1 | ± 4 | ± 2.1 | ± 4 |
| River Yenisei at Yeniseisk | ± 1.0 | 3 | ± 1.6 | ± 3 | ± 2.6 | ± 4 |
| River Angara at Irkutsk | ± 2.0 | ± 5 | ± 2.3 | 6 | ± 3.3 | 8 |

| | For a 30-year period. | | | | | |
|---|---|---|---|---|---|---|
| | Opening. | | Freezing. | | Free from ice. | |
| | Mean. | Maximum. | Mean. | Maximum. | Mean. | Maximum. |
| | ° | ° | ° | ° | ° | ° |
| River Obi at Barnaul | ± 0.8 | 2 | ± 1.3 | − 4 | ± 2.1 | + 4 |
| River Yenisei at Yeniseisk | ± 0.5 | ± 1 | (1) | (1) | (1) | (1) |
| River Angara at Irkutsk | ± 1.4 | ± 3 | ± 1.7 | + 4 | ± 1.5 | 5 |

[1] No information.

Investigation has shown generally that in the more central, and consequently more continental, portions of a country the times of freezing and opening of the rivers are subject to smaller annual variations. I give on p. 116 a table, taken from the work of Dr. Rykatschew, which shows the times at which the principal Siberian rivers begin and cease to be covered with ice. In this connection it must be observed that the following more extended series of observations are available: A series of one hundred years only for the river Angara; a series of eighty years for the Obi at Barnaul, and for the opening of the Yenisei at Yeniseisk. The observations for most of the other rivers extend over small periods of time. As the phenomena of the freezing and opening of the rivers are closely connected with the time of first occurrence, as well as with the duration of air temperatures below zero in the fall and of temperatures above the freezing point in the spring, I have also given in the table the following mean results: (1) The time of the first occurrence of a mean temperature of zero (for twenty-four hours); (2) the interval from the first day of zero temperature to the day of opening and freezing, respectively; (3) the number of days between the mean zero temperature of the spring and the fall. It would also be of interest to have data concerning the sum of temperatures below zero required for the freezing of the rivers, but we have such data only for the Angara, for which Dr. Woeikof derives the figure 99.8°, while for the Neva only 42° are required.

It appears from Mr. Rykatschew's maps, illustrating the simultaneous opening and freezing of the rivers, that the earliest opening of

Siberian rivers begins about the 21st of April in the southern portion of west Siberia, between the cities of Semipalatinsk and Barnaul. From there it moves to the upper part of the Yenisei, beginning later toward the east, or, if simultaneous, farther south. About the 1st of May the opening of the rivers already extends to the middle of the course of the Amoor. On the 21st of May the opening, beginning in the west near Berezov, extends eastward, bends at Yakutsk somewhat to the south, and turns on the shores of the Okhotsk Sea abruptly southwest towards Nikolaifsk on the Amoor. The Yenisei, in the lower part of its course, between Toorookhansk and the mouth of the river, throws off its covering of ice only at the beginning of June; the same is true of the rivers Yana and Kolyma in their lower course. Toward the end of June the mouth of the Lena becomes open, and partly that of the Yenisei. But even in the month of July some smaller rivers can be found covered with ice on the Taimyr Peninsula. According to the means deduced from the observations, the opening of the more important Siberian rivers takes place sixteen days after the occurrence of a mean temperature of the air of zero; for the smaller rivers the interval is twelve days.

The gradual onward motion of the boundary of the ice covering from the south to the north goes on more rapidly in the east. In eastern Siberia, in N. 50°, it takes place in a month, the motion northward being at the rate of 10° in nineteen days, but on one and the same parallel the opening is considerably retarded toward the east in the more southern parts of the country in comparison with the northern parts, and it is evidently connected with the direction of the isothermal lines and depends on local topographical conditions.

The covering of the rivers with ice, *i. e.*, the process of the formation of the ice on the rivers, is very interesting in Siberia, but, unfortunately, it has been investigated very little. It is known from the investigations of Messrs. Shchukin and Schwarz that the formation of ice in the Angara, and also in some other rivers, for instance in the Olokma, takes place not only on the surface but at the bottom as well.

Special mention should here be made of the Angara, as this river is distinguished from other Siberian rivers by several peculiarities. Forcing its way through the rocky shores of Lake Baikal, the Angara carries its waters, cold and clear as crystal, in rapid flow from the lake to the city of Irkutsk; and on this distance of only about 70 kilometers its bed has a fall of 30 meters, in other words, it has an average grade of 0.43 meters per kilometer. Along this whole distance the Angara does not receive a single important tributary, and represents a pure type of a lake river. From this it might be expected that its level would vary but slightly. It appears, however, as we shall see later, that the height of its water level is subject to

very considerable and abrupt variations. Another peculiarity of the Angara is its late freezing, which takes place about eighty days after the beginning of frosts, at a time when the cold reaches not less than —25°; it occurs more than a month and a half later than in other Siberian rivers situated in the same latitude. A third peculiarity of the Angara lies in the fact that its overflow takes place not in spring, summer, or fall, as is the case with other rivers, but in winter, at a time of the severests frosts, when the river is freezing. Dr. Stelling believes that the overflow of the Angara at the time of its freezing is due partly to the diminution of the velocity of the current arising from the friction of the water on the ice crust, and partly to the narrowing of its bed through the ice. The latter cause is probably the principal one. It is to be regretted that no exact data are available as to the distance over which the Angara below Irkutsk is covered with ice at an earlier period than at this city. The obstruction by ice in these portions of river, which freeze at an earlier time, are the main cause of the overflows.

I shall now give a brief extract from Dr. Schwarz's observations on the freezing of the Angara at Irkutsk in the winter of 1856–1857: On December 14 ice began forming along the banks; on the 18th, when the temperature of the air fell to —30.7°, while that of the water was +0.03, the whole river began to be covered with ice floes, and the ice on the banks extended to a considerable distance into the river. At the bottom of the river could be noticed numerous ice crystals which would, from time to time, break loose from the bottom and rise to the surface. On December 19, the temperature of the air being —35°, the ice crystals at the bottom disappeared, and the river continued to carry ice floes. Beginning with January 15, 1857, the water began to rise in the river, the temperature of the air being —11.7°. On the 18th the river overflowed all the low bank near the city; on the 19th the water rose to a height of 3 meters, and on the same day, the temperature being —24.1°, the main channel of the Angara became completely covered with an ice sheet. Nevertheless, the overflow of the river continued to increase up to January 24, and only on the 25th the water began to fall. It must also be noticed that the fall of the water, after the overflow has reached its greatest height, takes place very gradually, the water continuing to fall for a month. Thus it appears from the observations on the freezing of the Angara that ice crystals form at the bottom, that this goes on, with interruptions, in spite of the increasing cold, and that these crystals rise to the surface in the form of laminas which freeze on to the ice forming on the surface.

I add the following details as to the time of freezing of the Angara: In the year 1739 the river became completely covered with ice on January 9, simultaneously with Lake Baikal. This is a rare occur-

rence, as the Baikal usually freezes earlier. In 1751 there was a very heavy inundation at the time of freezing, January 8. In the winter of the year 1755 the river began being covered with ice only on February 2; the ice, however, was carried away seven times, and there was hardly any period of complete covering with ice. In the year 1870, when the river became covered with ice on January 15, a large part of the city of Irkutsk and many settlements along the Angara were inundated. The same thing occurred in 1887, when the river froze on January 18 and 19, and the overflowing waters carried large masses of ice with them. It is also worthy of notice that, from the very beginning of frost, *i. e.*, from the month of October, a heavy fog was constantly hovering over the Angara River. This fog disappeared only when the river became covered with ice.

Returning again to the results obtained by Dr. Rykàtschew, we find that the covering of the rivers with ice is subject to greater variations than the opening, and that it proceeds in the opposite order, *i. e.*, from the northeast to the southwest. First of all become covered with ice the small rivers of the Taimyr Peninsula, as early as in September. Next, about two weeks later, such rather considerable rivers as the Piasina, Indighirka, Yana, emptying into the Arctic Ocean, begin to freeze almost simultaneously, and the boundary of the ice covering advances pretty rapidly, forming two bends toward the south and southwest, one in eastern Siberia along the Amoor the other in west Siberia toward the upper course of the rivers Tom and Omi; an upward bend occurs along the valley of the Yenisei.

The formation of these bends in the progress of the ice sheet on the rivers depends both on the distribution of the air temperatures and on the slow cooling of the large mass of water in the rivers. To the same cause is due the late freezing of the northern parts of the other large rivers, viz., the Obi and the Lena, In its progress from east to west the covering of the rivers with ice is retarded about ten days for every 24° of longitude, while the southward march of the boundary of the ice sheet, from the polar circle to the fiftieth parallel, is accomplished, on an average, in thirty-one days.

As regards the duration of the ice covering, it varies between very wide limits. Thus, at the mouth of the Piasina the ice stays three hundred days, while in southern Siberia the duration is not over one hundred and sixty days. An exception is made by the Angara, which, after leaving the Baikal, for a distance of 7 kilometers, never freezes at all, owing to the rapidity of its current, and this in spite of temperatures of —40°, and of the fact that for a period of one hundred and seventy days the temperature always remains below zero. The same phenomenon occurs in the course of the Yenisei, in the narrow rocky passes of the Saian Mountains, and in a large number of small mountain rivers, which in some parts do not freeze at all, owing either to

the velocity of the current or to springs of warmer water emptying into their beds.

In the large rivers the ice stays, on an average, nine days longer than the duration of the normal temperature of zero; in the small rivers, only five days longer. The freezing of the large rivers takes place twenty-four days after the occurrence of a mean temperature of the air of zero; the freezing of the small rivers occurs seventeen days after this temperature. The extremes of temperature between which the freezing times oscillate are greater than those for the opening of the rivers, but far more constant. Thus the intervals between the earliest and latest openings and freezings are:

| For the— | Openings. | Freezings. |
|---|---|---|
| | *Days.* | *Days.* |
| Obi at Barnaul | 45 | 44 |
| Yenisei at Yeniseisk | 27 | 46 |
| Angara at Irkutsk | 50 | 61 |
| Lena at Kirensk | 28 | 21 |
| Lena at Yakutsk | 18 | 28 |

From the information gathered by the Polar Expedition of 1882–1884 it may be assumed that the opening of the mouth of the Lena, in N. 70° 23′, E. 126° 35′, occurs on May 25, and the covering of the river with ice on October 2, so that the river is only ninety-nine days free from ice. The mean value of the interval between the times of extreme openings is a little over a month for the rivers of Siberia, and the mean interval between the extreme freezings does not exceed thirty-five days, while for the rivers of Russia the latter interval amounts to fifty-two days. The constancy of the openings and freezings is particularly remarkable in the case of the Lena, as this river flows through a region having an extremely continental climate. Thus, the mean duration of the ice covering of the Lena, near Kirensk, is two hundred and three days; and in the course of the forty-two years for which there are observations, it happened only twice that the ice stayed fourteen days less, and only once that it stayed thirteen days longer than the normal duration.

As regards the thickness of the ice covering the rivers, the information is exceedingly scanty. We happen to know that in the lower course of the Yenisei the thickness of the ice in severe winters will reach 2.5 meters; and that on the Angara, at Irkutsk, on March 9, 1887, the greatest thickness was 1.14 meters, on the Baikal from 1.2 to 1.8 meters.

Concerning the variations of level in the rivers, we have the scientifically conducted observations of Dr. Stelling for the Angara, but only for 1886–1887. It appears from these observations that the water level of the Angara is subject to considerable variations in the course of the year, and that the annual curve differs decidedly from

those for the rivers of European Russia and of west Siberia. Thus, in 1887, the mean level of the Angara at Irkutsk (in meters) was as follows:

January, 4.35; February, 3.78; March, 4.57; April, 6.19; May, 6.08; June, 5.84; July, 5.35; August, 5.14; September, 4.92; October, 5.06; November, 5.44; December, 5.82.

These figures indicate by how many meters the water level of the Angara was below the mark established at the entrance to the Museum; they are daily means from three-hour observations taken 7 a. m., 1 p. m., and 7 p. m.

The daily observations showed that, beginning with the principal maximum which occurs toward the end of January, the water level of the river falls pretty uniformly to the second half of March; then, at the opening of the river, which takes place very rapidly and without overflow, a still greater fall occurs; but from the beginning of April to the beginning of June the water rises slowly. In July the rise becomes more pronounced, and in September the level reaches a second smaller maximum, arising from the great amount of precipitation in the Baikal region. At the expiration of the rainy period the water level of the Angara begins to fall slightly, continuing to do so with slight oscillations until the period of freezing. It thus appears that in spring, *i. e.*, at the time of the greatest overflows of the rivers of Russia and west Siberia, the height of the water in the Angara is usually least. This is largely due to the *small amount of snow* in the Trans-Baikal and on the mountains near Lake Baikal, which supply the affluents of this lake with water; also to *the slow thawing of the snow* during the cold and dry spring, and to *the heavy winds* which produce intensified evaporation accompanied by dryness of the air. On the other hand, during the latter part of the summer and the beginning of fall, when in Russia everybody complains of a lack of water, the Trans-Baikal country is visited by frequent rains. This abundance of precipitation is due to the monsoon which, in some years, extends into a portion of the Province (*Gubernia*) of Irkutsk. All the rivers then begin to rise, not excepting even the Selenga, if we may judge from the scanty information obtainable for this river. Even the level of Lake Baikal, in spite of the enormous extent of its surface will, in some years, rise appreciably.

Of the changes of level of other Siberian rivers, and of the times of greatest height of the water, we can judge only from the available data as to overflows and inundations caused by such overflows. Thus, beginning in west Siberia, in the basin of the Obi, the overflows of the rivers are usually observed in the spring. What contributes most to the intensity of the overflow is the early opening of the rivers, the great amount of the snowfall in winter, in particular if the snow falls on a previously frozen soil, the rapid approach of warm weather, or,

what is called, a "kind spring," which causes the simultaneous opening of many rivers. In the east, on the other hand, owing to the long and uninterrupted prevalence of the anticyclone in winter time, the winters are marked by an exceedingly small amount of snowfall, while in summer, during the reign of the summer monsoon which carries moisture from the Pacific Ocean, there is abundant rainfall, causing heavy overflows of the rivers, especially in the Amoor country. It is, however, not yet decided how far the rains caused by winds from the Pacific extend into the interior of eastern Siberia. But the heavy inundations occurring sometimes in the Province of Irkutsk in summer would seem to indicate that the influence of the monsoon occasionally reaches this territory.

To characterize the distribution of the precipitation over Siberia, I give the following results derived by Dr. Woeikof for the mean precipitation as percentage of the total annual amount:

| Place. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Semipalatinsk | 5 | 3 | 3 | 6 | 7 | 13 | 17 | 9 | 12 | 11 | 7 | 8 |
| Barnaul | 3 | 2 | 3 | 4 | 11 | 14 | 17 | 18 | 9 | 8 | 7 | 5 |
| Irkutsk | 4 | 4 | 3 | 5 | 6 | 14 | 17 | 13 | 12 | 8 | 7 | 8 |
| Kiakhta | 1 | 0.9 | 0.9 | 0.5 | 5 | 23 | 29 | 25 | 9 | 2 | 1.8 | 2 |
| Nerchinsk | 0.5 | 0.4 | 1.5 | 3 | 6 | 16 | 26 | 28 | 12 | 3 | 1.8 | 1.1 |
| Nicolaifsk on the Amoor | 3 | 3 | 4 | 6 | 8 | 10 | 10 | 18 | 21 | 8 | 7 | 2 |

It appears from these data that the amount of precipitation is distributed over the year more uniformly in western Siberia than in eastern Siberia. The lack of uniformity is particularly striking in the Trans-Baikal country.

For the Province of Irkutsk we have observations for a considerable period at the city of Irkutsk; these give for the annual distribution of the precipitation (in millimeters) the following figures: January, 19.2; February, 13.2; March, 10.0; April, 14.1; May, 26.5; June, 62.1; July, 72.1; August, 63.6; September, 41.6; October, 19.3; November, 15.8; December, 22.5.

But from year to year the monthly amount of moisture varies very much. Thus, in June the greatest mean precipitation was 161.6 mm. (in 1877); in July, 131.5 mm. (in 1878); in August, 107.8 mm. (in 1884), while in winter the maximum precipitation reached only 48.3 mm. in January, 1882. But there are years in which the precipitation for January and February is equal to zero.

The mean amount of precipitation at Irkutsk is as follows: Winter, 54.9 mm.; spring, 50.6 mm.; summer, 197.8 mm.; autumn, 88.1 mm.; in the driest summer there was 78.4 mm. (1888), and in the wettest 304.6 mm. (1883). Besides, the amount of precipitation in any given year is distributed very differently over the territory of

the Province of Irkutsk, as will appear from the following table for 1887:

| Place. | Winter. | Spring. | Summer. | Autumn. |
|---|---|---|---|---|
| North— | | | | |
| Bashchikovo | 26.1 | 42.2 | 89.2 | 141.4 |
| Usti-Kuta | 32.2 | 68.2 | 119.7 | 109.3 |
| West— | | | | |
| Birinsa | 41.0 | 42.6 | 81.8 | 96.6 |
| Cheremkhovo | 18.6 | 30.7 | 282.0 | 76.0 |
| East— | | | | |
| Irkutsk | 25.0 | 62.8 | 163.7 | 54.7 |
| Shimki | 15.1 | 52.4 | 252.1 | 40.7 |
| Southeast— | | | | |
| Tunka (1889) | 6.3 | 25.7 | 225.9 | 66.3 |

In the Amoor territory the want of uniformity in the distribution of the precipitation in the course of the year is still greater. Thus in 1878 the amount in millimeters was as follows:

| Place. | Winter. | Spring. | Summer. | Autumn. |
|---|---|---|---|---|
| Nerchinsk Mining Works | 4.7 | 24.0 | 233.4 | 103.4 |
| Blagovechensk | 0.0 | 83.1 | 204.6 | 48.2 |
| Khabarovka | 3.9 | 71.9 | 220.0 | 74.2 |
| Nikolaifsk | 67.5 | 77.3 | 177.1 | 155.1 |
| Vladivostok | 7.6 | 46.1 | 100.7 | 90.3 |
| Ilga Harbor (1880) | 29.3 | 198.5 | 270.4 | 348.8 |

To illustrate the non-uniformity of the distribution of precipitation during the summer months in different years, I give the following two years:

| Place. | 1878. | | 1880. | |
|---|---|---|---|---|
| | June. | August. | June. | August. |
| Nerchinsk | 49.3 | 98.7 | 149.1 | 159.8 |
| Blagovechensk | 36.8 | 71.7 | 56.0 | 119.5 |
| Khabarovka | 31.9 | 49.4 | 114.5 | 184.0 |

The abundance of moisture in the Amoor territory, accompanied at the same time by cloudy weather, low temperature, and reduced evaporation, is the cause of heavy inundations in summer. Although the ratio of the amount of precipitation in the wettest to that in the driest summer month is considerably less at Irkutsk than in the Trans-Baikal, yet it is much greater than at Yeniseisk and other localities situated farther west and agreeing more closely in this respect with Russia.

I now proceed to give a brief account of the data concerning inundations available for Siberia. I begin in the west. An unusually large inundation took place in the spring of the year of 1857 along the western affluents of the Obi. It began on the river Vagai and its tributaries. In the same spring an unusual increase of water was also noticed in the rivers Irtish, Tobol, Toora, Omi, and others. Thus,

on May 20, the river Irtish overflowed its banks near Tobolsk; on June 1 the water had there risen to a height of 6 meters above its mean level, flooding four hundred houses. The waters began falling on June 10. The highest rise of the water in the Irtish, near the city of Omsk, was only 2 meters above the mean level. In the river Toora the water often rises to a considerable height at the time of the spring floods, which will continue from thirty to seventy-five days. At the greatest of these floods, in 1854, 1857, and 1870, the waters of the Toora rose from 6.5 to 9 meters above its ordinary level near the cities of Toorinsk and Tioomen. The greatest inundation of the river Tom, near Tomsk, is said to have taken place in the year 1804, when the ice in the river began to move on May 11, and on the 12th the overflow had reached such dimensions as to inundate five districts in the lower portion of the town. On May 13 and 14 the water rose still 0.75 meters higher, carrying ice. Altogether, the water rose 5 meters above the ordinary level. Beginning with May 15, the water fell rapidly. Next to this the heaviest inundation of the Tom occurred in 1843, from April 20 to 26, and in 1887, from April 25 to 27.

When the ice opens on the Yenisei River the city of Krasnoyarsk generally suffers less from the floods than the city of Yeniseisk, which is situated farther down on the river. At Yeniseisk the overflows are particularly heavy when the ice opens at the same time in the Yenisei and in the Upper Toongooska (Angara) and Tasieieva. Usually, however, the ice opens six days later on the former and twelve days later on the latter than on the Yenisei. In the course of the last sixty years there were in all eleven inundations, of which those in the years 1800 and 1857 were the most destructive. The Yenisei overflows twice a year. One overflow usually occurs in spring, in the latter part of May, and is called the "snow water." In some years the water, at the time of the spring overflow, will reach a height of 14 meters above the mean level. The other overflow, which is less important and is called "root water," occurs generally toward the end of June; it is due to the snow melting in the mountains.

In 1870 a heavy summer inundation occurred in the Nizhnee-Oodinsk district of the Province of Irkutsk, in the basin of the rivers Ooda and Ya, which are affluents of the Angara. The former overflowed its banks on July 5 and inundated almost the whole valley through which it flows, the water rising particularly in narrow places hemmed in by rocks. The city of Nizhnee-Oodinsk was the principal sufferer; in the various villages situated along the valley of the Ooda, ninety-nine houses, two mills, and a sentinel's box were destroyed and carried away; two men and a great number of cattle were killed. In the river Ya and in its right-hand tributary, Aza, the water began rising on July 4, and on the 9th the waters rushed over the banks with such

rapidity and such incredible power that an "oboz" (row of wagons for transportation) laden with tea, standing near the bank, did not have time to escape and was carried away by the flood. On July 8 a heavy overflow began also in the valley of the Biriusa, an affluent of the Ooda.

The Angara, as mentioned above, has its overflow near Irkutsk in winter. This winter high water is an annual phenomenon, though varying in intensity more or less from year to year. There are no exact data as to how far down the river this winter overflow extends. It is known, however, that at the village Bratsky-Ostrog, situated on the Angara, 310 kilometers below Irkutsk, the river overflows at the time of the breaking up of its ice in the spring, and inundates the settlements situated on its banks.

The difference between the summer and winter water level of Lake Baikal does not generally exceed 1 meter, though sometimes it amounts to as much as 3 meters. During the very rainy summer of the year 1869 the waters of Lake Baikal rose 4.5 meters above the usual level. Considering the great dimensions of this lake (about 34,180 square kilometers), this enormous increase of water gives an indication of the immense quantities of water which the Baikal must receive from the rivers emptying into it. According to the Irkutsk records, there were in that summer twenty-four cloudy days in July and twenty-one in August. Now, on an average, there corresponds to every rainy day the following amount of precipitation: In June, 2.83 millimeters (maximum, 17.4); in July, 5.87 (maximum, 27.6); in August, 6.49 (maximum, 64.6); and in September, 0.84 (maximum, 7.4). It follows that the rise of the water level of the Baikal was directly dependent upon the great amount of precipitation received in the surrounding country at the time of the summer monsoon; this precipitation being carried into the Baikal by the numerous rivers emptying into it, of which there are as many as three hundred and thirty-six. Among these affluents there are three of considerable size, viz., the Selenga, the Upper Angara, and the Bargoozeen. The only outflow for the waters of the Baikal is furnished by the Angara. The area from which the affluents of Lake Baikal collect their waters has been computed as 320,500 square kilometers.

The river Lena, in its upper course, does not overflow when the ice breaks; a small increase of its water level occurs in the second half of May, when the snow melts in the mountains. The time of greatest increase of water is usually in the middle of July; it is due to the heavy rains occurring at this time. Destructive inundations are, however, rarely caused by this high water; those best known are the inundations of 1816 and 1864. In the latter year the water of the Lena, near the city of Verkholensk began to rise rapidly on July 11; on the 13th it overflowed the banks and inundated the mea-

dows, islands, and the lower end of the city; on the 17th the river was again confined to its banks. The whole month of July of the year 1864 was rather cold for summer weather; the same is true of the month of August, which had a mean temperature of only 8.4°; on September 3, at 5 a. m., the thermometer stood at —3.8°. There were twenty-two rainy days in July; in August it rained twelve times and snowed twice, the water in the Lena increasing again rapidly from August 8 to 14.

In the middle course of the Lena, in the Kirensk district, we find, besides the summer high water, overflows at the time of the opening of the ice. Thus in 1870 the ice on the Lena near the city of Kirensk began moving on April 30; the river overflowed its banks and inundated part of the city; and when, on May 1, the ice began also to move on the right-hand affluent, Kirenga, which empties into the Lena near the city, the water rose still higher, doing a great deal of damage in the city. The overflow was especially great in the villages of the Vitimsk district, situated along the Lena, below the city of Kirensk.

The farther we go eastward into Siberia the less frequent and destructive are the spring inundations, owing to the small amount of snow that falls during the winter months in the Trans-Baikal and the Amoor territory. In the latter country deep snow is found only in the lower course of the Amoor. But, at the time of the summer monsoon, the abundant precipitation causes heavy summer inundations. During the years 1855 to 1882 eight great inundations were observed in the basin of the Amoor; the most destructive of these was the one in 1872, which came from the upper course of the Amoor. At Stretensk the water level reached its greatest height on July 9, at Blagovechensk on the 15th and 16th. At the latter place the water rose 10 meters above the ordinary level, in spite of the fact that the river valley is there rather open and the banks of the Amoor, in particular the left-hand bank below the city, are lowlands. But, in the Maly-Khingan mountains the water in the Amoor rose 16 meters above its mean level. On July 19 the water began to fall near Blagovechensk. Out of twenty-seven settlements (*stanitsa*), situated on the left bank of the upper Amoor, ten were carried away by the flood. A second, and very considerable, rise of the waters of the Amoor occurred in the month of August of the same year, coming from the rivers Argoon and Zeia. Thus on August 9 and 10 the water of the Amoor rose 17.5 meters(!) above the ordinary level at the Pokrovsky settlement; at the city of Blagovechensk the greatest height of the water occurred on August 15 and 16, but the height reached was less than in July.

Heavy floods were also observed in the river Zeia in 1861, when the water of this river rose three times in the course of the same sum-

mer—from June 10 to 13, from July 20 to August 2, and from August 31 to September 10.

In the southern portion of Ussurysk territory the heaviest inundations occurred in the years 1861, 1863, 1868, and 1873. The overflows of the Amoor begin usually after more or less prolonged rains. But as the amount of precipitation is not uniformly distributed, the inundations are most heavy sometimes in one, sometimes in another part of the Amoor and Ussurysk territory.

As regards the current velocity and the discharge of the Siberian rivers, we have, besides the scientific determination of these quantities made by Dr. Stelling for the Angara, some observations on smaller rivers, viz., the Tobol and the Toora. These observations were made with a view to decide the question as to the sufficiency of the supply of water in these rivers for navigation purposes. Observations were also made on some other small rivers, viz., the Oziornaia, Lomovataia, Jazevaia, Maly Kas, and Bolshoi Kas, in connection with the investigations for the purpose of connecting the Obi with the Yenisei.

The observations of Dr. Stelling at Irkutsk showed that the mean water level of the Angara at this point has an elevation of 453.3 meters. He also found the results tabulated as follows:

| | Width, in meters. | Greatest depth, in meters. | Area of cross-section, in square meters. | Velocity of current, in meters per second. | | Quantity of water flowing through, in cubic meters, per second. |
|---|---|---|---|---|---|---|
| | | | | Mean. | Max. | |
| At the Znamensky Convent, below the mouth of the river Irkoot | 327 | 7.15 | 1,365 | 1.67 | 1.98 | 2,276 |
| At the Troitsky Ferry | 577 | 5.44 | 1,905 | 1.22 | 1.90 | 2,321 |
| At the same place, when the water was higher, July 21 | 597 | 6.06 | 2,219 | 1.26 | ........ | 2,793 |
| Same place, under the ice | 600 | 5.47 | 1,920 | 0.89 | ........ | 1,709 |

At the Troitsky Ferry, where the current velocity and the depth of the river are less, while the area of the cross-section is greater, more water flows by than farther down the river, at the Znamensky Convent. When the water-level is higher, the dimensions of the river, its depth, are increased, and so is the velocity of the current and the quantity of water flowing by (discharge).

It is to be hoped that, in connection with the proposed railway line through Siberia, the Ministry of Roads of Communication will at once institute investigations of a similar kind for the other important rivers of Siberia.

The annual discharge of the Angara shows a maximum in the fall and a minimum in the spring.

The amount of water carried by the Angara in the year 1887 was, according to the results obtained by Dr. Stelling, in cubic kilometers, as follows:

*Discharge of the Angara for 1887.*

| Period. | Discharge per— | |
|---|---|---|
| | Month. | Day. |
| January | 7.056 | 0.2276 |
| February | 5.642 | 0.2015 |
| March | 4.920 | 0.1587 |
| April | 4.629 | 0.1543 |
| May | 4.976 | 0.1605 |
| June | 5.262 | 0.1754 |
| July | 6.442 | 0.2078 |
| August | 6.950 | 0.2242 |
| September | 7.311 | 0.2437 |
| October | 7.161 | 0.2310 |
| November | 6.069 | 0.2023 |
| December | 5.475 | 0.1766 |
| Total annual discharge | 71.893 | ........... |
| Average daily discharge | ........... | 0.1970 |

For the smaller rivers mentioned above, the following brief data are available with regard to the current velocity and the discharge:

| Rivers. | Fall of the river in the whole investigated distance, in meters. | Mean current velocity, in meters per second. | Discharge per second, in cubic meters. |
|---|---|---|---|
| Toora | 7.6 | .... | 246.70 |
| Tobol | 2.6 | .... | 357.40 |
| Osiornaia | .... | 0.23 | 17.50 |
| Lomovataia | 12.3 | 0.46 | 9.00 |
| Yasevaia | 3.4 | 0.11 | 0.84[a] 0.45[b] |
| Maly-Kas | 15.2 | 0.20 | 1.75[a] 8.90[b] |
| Bolshoi-Kas | 39.8 | 0.02 | 26.20 |

[a] Upper portion. [b] Lower portion.

In concluding, the regret must be expressed that at present only a very small number of stations, separated by immense distances, exist in Siberia for meteorological investigations; and that the number of stations having observations for a longer period is still more limited. It is to be hoped that the Magneto-meteorological Observatory established at Irkutsk in 1886 will do all in its power to extend the sphere of its activity, and that it will turn its attention also to the investigation of the rivers. For there are many questions connected with the rivers still awaiting a final solution; such, for instance, as the cause of the formation on many Siberian rivers, during the severest cold, of so-called "propariny," *i. e.*, open places in the ice, which may sometimes for a while become covered with a very thin crust of ice; the formation of foam on the rivers; the causes why some rivers do not freeze; the formation and thickness of the ice on rivers, and in particular on Lake Baikal, where, as is well known, a regular cannonade is sometimes heard in winter, arising from the constant formation of fissures in the ice, which afterward move away; the temperature of the water in the rivers; the degree to which the soil freezes; the snow sheet covering the country in winter; and, so on. All these are problems hardly as yet touched by investigation.

*Table from Rykatschew's work, showing the times the principal rivers begin and cease to be covered with ice.*

| Name of river and place of observation. | North latitude. | Longitude east of Greenwich. | Heights above the sea level, in meters. | Mean dates of— Opening. | Mean dates of— Freezing. | Mean number of days free of ice. | Days of zero temperature in — Spring. | Days of zero temperature in — Autumn. | Interval between— The day of opening and the day of zero of temperature. | Interval between— The day of freezing and the day of zero of temperature. | Interval between the zero temperature of spring and autumn. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | ° ′ | ° ′ | | | | | | | | | |
| (1) Obi at Barnaul | 53 20 | 83 47 | 161 | Apr. 26 | Nov. 9 | 197 | Apr. 14 | Oct. 21 | +12 | +19 | 190 |
| Obdorsk | 66 31 | 66 35 | 26 | June 4 | Oct. 28 | 146 | May 21 | Sept. 26 | +14 | +32 | 128 |
| (2) Yenisei at Abikarsky | 54 15 | 91 27 | 175 | Apr. 30 | (1) | (1) | Apr. 6 | Oct. 21 | +24 | (1) | (1) |
| Krasnoyarsk | 56 01 | 92 49 | 152 | Apr. 30 | Nov. 12 | 197 | Apr. 10 | Oct. 18 | +20 | +25 | 191 |
| Yeniseisk | 58 27 | 92 06 | 91 | May 6 | Oct. 17 | 195 | Apr. 24 | Oct. 16 | +12 | +32 | 175 |
| Angara at Irkutsk | 52 17 | 104 16 | 454 | Apr. 7 | Jan. 10 | 278 | Apr. 8 | Oct. 18 | − 1 | +84 | 193 |
| (3) Lena at Kirensk | 57 47 | 108 03 | 240 | May 11 | Oct. 20 | 162 | Apr. 25 | Oct. 8 | +16 | +12 | 166 |
| Yakutsk | 62 01 | 129 43 | 113 | May 20 | Oct. 19 | 152 | May 5 | Sept. 27 | +17 | +27 | 145 |
| (4) Amoor (Shilka) at Stretensk | 51 58 | 116 35 | ? | May 5 | Nov. 4 | 184 | Apr. 24 | Oct. 6 | +10 | +29 | 165 |
| Blagovechensk | 50 15 | 127 38 | 154 | Apr. 28 | Nov. 10 | 196 | Apr. 11 | Oct. 18 | +17 | +23 | 190 |
| Nikolaifsk | 53 08 | 140 45 | 0 | May 22 | Nov. 12 | 174 | Apr. 27 | Oct. 21 | +23 | +20 | 177 |

| Name of river and place of observation. | Opening. Earliest. | Opening. Latest. | Freezing. Earliest. | Freezing. Latest. | Interval between earliest and latest— Opening. | Interval between earliest and latest— Freezing. | Number of days free from ice. Minimum. | Number of days free from ice. Maximum. |
|---|---|---|---|---|---|---|---|---|
| (1) Obi at Barnaul | Apr. 12 | May 27 | Oct. 17 | Nov. 30 | 45 | 44 | 227 | 166 |
| Obdorsk | May 20 | June 18 | Oct. 14 | Nov. 15 | 29 | 32 | 166 | 123 |
| (a) Tobol at Tobolsk | Apr. 11 | May 17 | Oct. 22 | Dec. 1 | 43 | 40 | 220 | 184 |
| (b) Tom at Tomsk | Apr. 18 | May 20 | Oct. 20 | Nov. 17 | 32 | 28 | 205 | 171 |
| (2) Yenisei at Yeniseisk | Apr. 22 | May 19 | Nov. 2 | Dec. 16 | 27 | 46 | 237 | 176 |
| (a) Angara at Irkutsk | Mar. 14 | May 3 | Dec. 13 | Feb. 12 | 50 | 61 | 313 | 240 |
| (3) Lena at Kirensk | Apr. 27 | May 25 | Oct. 10 | Oct. 31 | 28 | 21 | 176 | 149 |
| Yakutsk | May 5 | May 26 | Oct. 8 | Nov. 5 | 18 | 28 | 170 | 138 |
| (4) Amoor at Blagovechensk (2) | Apr. 19 | May 10 | Nov. 6 | Nov. 15 | 21 | 9? | (1) | (1) |
| Nikolaifsk | May 11 | May 30 | Oct. 30 | Nov. 19 | 19 | 20 | (1) | (1) |

1 No information.

2 The observations at Blagovechensk extend only over nine years.

## 6—REGIMEN OF THE RHINE REGION: HIGH-WATER PHENOMENA AND THEIR PREDICTION.

M. VON TEIN.

The regimen of a river, as well as the appearance and progress of high-water phenomena, it is known, bear a close relation to the physical characteristics of the region, particularly the relief of the ground, the extent of the drainage area and the climatic elements dependent on the former, especially the distribution of the rainfall. A consideration of the hydrological phenomena of a region requires, therefore; at first a glance at its general physical characteristics.

The Rhine, although it drains scarcely an area of 160,000 square kilometers with its tributaries, extends diagonally through the principal parts of middle Europe, the Alps, the mountain region of central Germany, and the Netherland lowlands. Its drainage area has therefore an uncommonly great variety of relief. From the chain of the central Alps, towering to a height of 4,000 meters, forming the southern boundary, the region falls toward the Swiss and upper Swabian highland, of which the average elevation is 500 meters, and rises again to over 1,000 meters in the Jura, the Black Forest, and the Vosges, the most considerable elevations of which bound it on the west and north. Sunk between the Black Forest and the Vosges lies the upper Rhine lowlands traversed by the Rhine, while on the verge of the mountain range roundabout spreads extensive terrace and the flat valleys, forming the region of the entrance of the great central mountain rivers—the Neckar, Main, and Moselle.

On the north the mountains of the lower Rhine, traversed by the Rhine in a deeply eroded valley, shut off the central mountains toward the north German highland to which the lowest parts of the drainage area belong. The Rhine flows here in its upper course through high mountains, a high tableland, and the central mountain range; in its middle course through a low plain and then, for the first time, after breaking through the great chain of the central mountain range, begins its lower course with its entrance into the north German lowlands.

The grouping of these surfaces forms a many-branching river system among the streams of the Alps, of the central mountain region, and the lowlands, a distinction which, for the regimen of the drainage area, is of the greatest significance.

The Rhine assembles the streams of the Alpine country and the borders where it leaves the Swiss highland; here the Alpine part of the tributary region ends, which, with considerable rainfall, has also great capacity for retaining water.

The precipitation in the Alps for the greater part of the year being

in a solid form, is stored up in the winter and in the warm season is given up as melted snow more or less freely, and the run-off is modified by a considerable number of lakes around the border of the Alps. The region of the central mountain rivers begins with the breaking of the Rhine through the Jura or with its entrance into the uppe Rhine lowlands at Basel. At first the river receives only small streams, for, on both sides parallel to it and only a short distance from it, the Black Forest range and the Vosges turn their steep flanks toward it, while on the other side they drain off toward the Neckar and the Moselle. The Rhine in this, the second principal part of its course, traverses a distance of more than 300 kilometers before the great central mountain river, the Neckar, empties into it, and then, in relatively rapid succession in a distance of about 150 kilometers by the river, there come into it the Main, the Nahe, the Lahn, and the Moselle. In the region of these central mountain range rivers, the Black Forest range, and the Vosges, the rainfall is still very considerable. The snow covering in the course of the winter, from repeated thaws and according to its height and density and the accompanying circumstances of its melting, occasionally produces great floods in the streams in a short time. Persistent rain and thunderstorms often carry the wet period into midsummer, and in autumn in the high central mountain region the precipitation reaches its maximum; the feeding out of water to streams diminishes very considerably in consequence of the great loss of water by evaporation and absorption by plants. The third division of the Rhine drainage area, comprising the streams of the lowland from about the mouth of the river up to the lower Rhine Mountains, is relatively small and not of much importance as regards the water which flows from it into the Rhine. The region is under the moderating influence of the ocean climate, so that sudden changes of weather and their consequences are scarcely perceptible in the rivers.

The changes in river stage along the Rhine occur as follows: along the upper course and down to the Neckar the flow from the Black Forest range and the Vosges is, as a rule, not considerable enough to make any appreciable change; it is completely controlled by the water from the high mountain region; very little water comes in during the winter; there is considerable addition of water in the spring with the disappearance of the snow on the lower mountains; there is an increased flow at the beginning of summer as the melting advances up the high mountains; and finally, again a diminishing supply of water, until toward spring, in spite of the continuing additions of glacier water. There is, therefore, a tolerably steady increase from winter, not, however, without this regular course being varied and broken into at times by heavy floods due to great rainfall such as often accompanies the Föhn wind. In the section of the Rhine

between the Neckar and the Moselle, under the influence of the great central mountain range rivers, a change occurs in the order of river-stage variation which begins to be first apparent at the entrance of the Neckar, and still more so at Mainz after the entrance of the Main. Below the mouth of the Moselle there is a complete reversal of conditions. The diminished supply of water toward the end of winter becomes apparent at Mainz as a secondary maximum; below the mouth of the Moselle it reaches the summit of the annual curve; at this point, on the contrary, the summer high water of the upper Rhine, which is seldom strongly reinforced from the central mountain range region, sinks to a moderate rise, while on the other hand in February and March, among the poorest months in the year in water above the entrance of the Neckar at the mouth of the Moselle, the highest stages occur. In the lower Rhine the stages of water thus produced by the Neckar, Main, and Moselle no longer change, but are rather intensified by the tributaries.

A like great difference in the behavior of the various parts of the Rhine appears, especially during the prevalence of high water. It is in a measure a rule, that considerable flood waves in the upper part of the drainage area appear along the middle and lower courses as inconsiderable rises, and that again, flood phenomena appear in which the upper courses of the river have no part. The absolute high waters observed so far in the various divisions of the river have occurred in entirely different periods of high water. Excessive and disastrous high waters affecting the river in all its parts scarcely ever occur; at least they are exceedingly rare. The high water is always caused by extraordinarily great rainfalls, which, as experience shows, occur over only very restricted areas and in isolated cases, when, with great downpour, melting of snow occurs simultaneously over a great part of the drainage area; under these circumstances the tributary basins cause various combinations of high-water waves. It frequently happens that the highest stage of a rise in the middle Rhine occurs when at the same time the upper Rhine is still rising and the apex of the rise comes down as far as the entrance of the Neckar, and by that time the high water in the middle and lower Rhine is long past. The behavior of the tributaries has a very important bearing on the course of high water in the main stream, especially if the flood waves from the last two great tributaries, the Main and Moselle, both of which in length of course, extent, and nature of drainage area show great similarity, succeed each other in such a way that the wave from the Main comes in on the crest of the wave from the Moselle at Coblentz. The subsequent flood wave from the upper Rhine causes in the middle and lower Rhine, and in fact from the Neckar down, only a delay in the recession of the water.

It is a fact well known from experience, and it finds explanation in

the preceding remarks, that the Rhine region, as compared with the neighboring regions, is naturally protected in a higher degree against the frequent occurrence of disastrous high waters, because many opposite conditions must act together to produce such a high water.[1] Nevertheless, the occurrence of such an event in such a closely cultivated region as this is, means, in every case, a great damage to agricultural interests. Ten years ago, after the memorable high water in the winter of 1882–'83, the German Imperial Government established a commission to investigate the Rhine and consider the best methods of artificial protection against floods. This commission reported in 1891 to the Chancellor of the Empire the results of its eight years' activity. In the report the fact is emphasized that, in view of the dense population and minutely cultivated parts, it is out of the question to try combating the might of high waters by measures calculated to restrain the waters on a large scale, aside from the fact of the enormous expense of such a proceeding—out of all proportion to the advantages to be derived—and other vested interests of the population of the region would be thereby greatly damaged. High water protection, in addition to measures of protection by a suitable treatment of the course of the river, and by the leveeing of frontages threatened by floods, must remain limited to deriving a correct knowledge as to what must be withstood from the beginning and throughout the course of dangerous rises. This knowledge consists, up to the present time, in a carefully organized service for the dissemination of information regarding high water, by telegraph principally. What still remains in this domain worth gaining, and which the commission in investigating the Rhine proposes to attain, is the numerical determination of water heights to be reached during rises along the middle and lower courses of the Rhine, and along the upper course and its larger tributaries, and also the establishment of a system of high water predictions. This, for the population interested, would doubtless be more valuable than simply information as to the stages of water at places on the river above. Considering the extraordinary difficulties in the way of forecasting, in view of the changing regimen of the river just described and the complex phenomenon of a high water, and the lack of previous hydrological investigation (which heightens the difficulty), high water predictions have not yet been attempted. In the year 1886, on the suggestion of the Imperial Commission before mentioned, the *Central Bureau für Meteorologie und Hydrologie* of Baden,

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[1] The regimen of the Rhine region and the behavior of the river during high water is treated of very fully in the work *Der Rheinstrom und seine wichtigsten Nebenflüsse*, Berlin, 1889, issued from the *Central Bureau für Meteorologie und Hydrographie* in the Grand Duchy of Baden. The high waters occurring in this century are treated of very fully in the first volume of *Ergebnisse der Untersuchung der Hochwasserverhältnisse im Deutschen Rheingebiet*, Berlin, 1891.

at Carlsruhe, was designated as the proper institution to be entrusted with the investigation of hydrological phenomena during the inception and progress of great rises in the Rhine and its tributaries, so as to lay a firm, scientific foundation, on which, perhaps, satisfactory high-water predictions may in the future be based.

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## 7—THE NILE.

W. Willcocks, M. I. C. E.

The recent explorations of Lugard and Baumann have completed the work originated by Burton and carried on by Speke, Grant, Baker, Stanley, Gordon, Junker, and Schweinfurth, and we can now follow the course of the Nile from its springs far south of the equator to its termination north of the thirtieth parallel of latitude. A river so regular and gentle in its movements as the Egyptian Nile can only be understood after a study of its sources of supply, and the early part of this paper must, therefore, be devoted to the hydrology of the Nile Valley. On the accompanying plan and longitudinal section are detailed the observed times and heights of high and low supply, and the times and proportions of rainfall. From the sea to Wady Halfa the Egyptian Irrigation Service has supplied the figures; from Wady Halfa to Khartoum Sir John Fowler's surveys and levels have been used, with a correction of 13 meters to suit the figures of the irrigation department at Wady Halfa; while to the south of Khartoum the distances and heights have been taken from the observations of Gordon Pasha's staff when he was governor of the Soudan. To Lake Victoria a mean level has been applied. I take this opportunity of acknowledging my thanks to Bonola Bey, the Secretary of the Khedivial Geographical Society of Cairo, for the assistance I have received from him. I am at the present moment engaged in making a study of the Nile for the Egyptian Government. This study will not be completed before the end of December, but on the invitation of your committee, with the consent of Mr. Garstin, Under Secretary of State for Public Works in Egypt, I have collected all the information which is at my disposal to-day and have embodied it in this paper.

The Nile drains nearly the whole of northeastern Africa, an area comprising 3,110,000 square kilometers. Its main tributary, the White Nile, has its source to the south of Lake Victoria and has traversed over 3,500 kilometers before it is joined by the Blue Nile at Khartoum. From the junction onward the river is known as the Nile, and after a farther course of 3,000 kilometers flows into the Mediterranean Sea by the Rosetta and Damietta mouths.

Lake Victoria, covering an area of 70,000 square kilometers is the

first reservoir of the Nile. The equator passes through this lake, which lies in the region of almost perpetual rains and receives an excessive supply of water from its western tributaries, from subsoil springs, and heavy rainfall. Stanley considered the discharge of the White Nile as it left Lake Víctoria as one-third greater than that of the Tangourie, the principal affluent of the lake. Judging from recorded observations farther down the river, the mean discharge of the lake is probably 750 cubic meters per second. Shortly after leaving Lake Victoria, the White Nile descends the Ripon Falls on a width of 400 meters and a drop of 4 meters. Lake Victoria lies about 1,130 meters above sea level and is 500 meters higher than Lake Albert. Between these lakes, on a distance of 480 kilometers the White Nile (known here as the Somerset) traverses at first the succession of swamps known as the Ibrahimia Lake, and then taking the character of a mountain torrent precipitates itself into the southeast corner of Lake Albert. The survey of Lake Albert, which has an area of 4,500 square kilometers, was made in 1877 by Mason Bey, and he recorded the fact that the lake was 1.20 meters below its high-water level. The rainfall of that year was deficient in the whole of the Nile Valley, and the summer supply of the Nile was the lowest of which there is any record. In July, 1892, Capt. Lugard noticed that Lake Victoria was 2 meters above its normal level after the heavy rains of that year, and the summer supply of the Nile in 1893 is so high that it has only once been exceeded, according to our records. Lake Edward, with an area of 5,000 square kilometers and a height above sea level of 880 meters, is a feeder of Lake Albert. After leaving Lake Albert the White Nile flows for 200 kilometers in a deep, broad arm with scarcely any slope and scarcely any velocity as far as Dufflé, and then after a short, troubled course tosses over the Fola rapids on a width of 90 meters, and continues as a torrent for another 200 kilometers to a short distance south of Gondokoro. At Gondokoro the river is 2 meters deep at low water, and only 4.50 meters deep in flood, the discharge ranging between 500 and 1,600 cubic meters per second. The regulating effect of the great lakes is well felt here. We are indebted to Emin Pasha for this information. It is one of the keys for understanding the flow of the Nile, and will be dwelt on later in this paper. At Gondokoro the river is at the lowest in winter, it begins to rise about April 15, and reaches its maximum between August 15 and 30.

From Gondokoro to Bôr, a distance of about 120 kilometers, the river keeps in one channel and has a rapid fall, while from Bôr to the mouth of the Gazelle River, on a farther reach of 380 kilometers, the river divides into numerous channels and has a very feeble slope. The main channel is known as the Bahr el Gebel (the mountain stream), and is the one always used for navigation. In this reach are the "sadds" or dams of living vegetation which, at times, are

capable of barring the surface and completely blocking navigation. The Gazelle River joins the White Nile on its left bank and has a feeble discharge in summer, but exceeds the Bahr el Gebel in flood. At the junction of the Gazelle River and the White Nile is a lake of an area of some 150 square kilometers in summer. During this latter period, in years of scanty rainfall, all this part of the river acts as an evaporating basin and a source of loss to the Nile. The waters of the river likewise become polluted here with decaying vegetable matter which, at certain times of the year, imparts a green color to the Nile as far north as Cairo. One hundred kilometers below the Gazelle River the White Nile is joined by the Saubat River on its right bank. During flood this river has a discharge nearly equal to that of the White Nile above the junction, while in summer it has a feeble discharge and is occasionally quite dry. From the junction of the Saubat to Khartoum, on a length of 900 kilometers, the White Nile has a mean width of 1,700 meters, a depth varying from 5 meters in low supply to 7.5 meters in flood, and a sluggish stream. The action of the current is always on the right bank owing to the prevailing northwest winds, and this action is continued during the whole of the remaining course of the river as far as the sea. The soil from the Saubat River to Khartoum is light and friable, and the White Nile, in spite of its moderate velocity, has a width 160 times its depth in flood.

At a point 3,009 kilometers from the sea, and 390 meters above it, is the town of Khartoum, where the Blue Nile from Abyssinia joins the White Nile. The Blue Nile has its sources in the mountains of Abyssinia, where Lake Tsana—with an area of 3,000 square kilometers and height above sea level of 1,780 meters—is another reservoir of the Nile. The Blue Nile has a length of 1,350 kilometers. This river is comparatively clear in summer, but during flood, *i. e.*, from the beginning of June to the end of October, it is of a reddish-brown color, highly charged with alluvium. The Khartoum Nile gauge, which was read from 1869 to 1883, used to stand on the Blue Nile about 5 kilometers above its junction with the White Nile, and its recorded reading are not exact records of the Nile. In flood the discharges of the two rivers are equal, but in summer the White Nile is the main source of supply. The Nile here has a mean range of 6.50 meters between high and low supply, with a maximum of 7.80 meters and a minimum of 5.30 meters. From comparisons with the Assuân gauge, and observed discharges referred to the Khartoum gauge, I calculate that the high supply varies between 12,900 and 5,200 cubic meters per second, with a mean discharge of 8,000 cubic meters per second, while the low supply varies between 1,500 and 320 cubic meters per second, with a mean discharge of 550 cubic meters per second. April is the lowest month and September the highest.

At a distance of 90 kilometers down stream of Khartoum is the sixth cataract. Here the Nile descends 6 meters on a length of 18,000 meters. At a distance of 320 kilometers from Khartoum the Nile is joined by the Atbara River. This latter is another stream fed by the Abyssinian torrents, and though dry in summer is a considerable river in flood. Heavily charged with volcanic detritus it provides the greater part of the rich, fertilizing mud which the Nile carries in flood. The Atbara has a range of 8 meters, and from calculations and comparisons I estimate that its floods range between 4,900 and 1,600 cubic meters per second, with a mean high flood of 3,400 cubic mèters per second. It is in flood from July to October, with its ordinary maximum in August. Below the Atbara junction the Nile has no tributary, and flows throughout its 2,700 kilometers to the sea a solitary stream. Traversing one of the greatest deserts on the globe, it is the sole source of life and vigor to whatever exists on its banks.

Twenty-four kilometers downstream of the Atbara junction is Berber, and 45 kilometers downstream of Berber is the beginning of the fifth cataract, which has a length of 160 kilometers and drop of 66 meters, with three principal rapids, the Solimania, Baggâra, and Mograt. The village of Abu Hamed is situated at the foot of this cataract. Between Abu Hamed and Dongola is the fourth cataract, which begins at a point 100 kilometers downstream of Abu Hamed, and has a length of 110 kilometers, with a drop of 49 meters. In this series of rapids are the Um Derâs and Guerendid. Between the fourth and third cataracts is a reach of 310 kilometers on a slope of 1 : 12,000. On this reach is the town of Dongola. The third cataract has a length of 70 kilometers and drop of 11 meters with the Hannek and Kaibar rapids, surveyed and leveled by De Gottberg in 1857. Upstream of the Hannek rapid on the left bank of the Nile is the termination of the long depression in the deserts, which goes by the name of Wady el Kab, and is considered by many as lower than the Nile valley. Between the third and second cataracts is an ordinary reach of 130 kilometers. West of this part of the Nile are the Selîma Wells, and, according to some travellers, an old abandoned course of the Nile slightly above the present high level of the river. This waterless river terminates in the Oasis of Berys, which is separated from the Khargeh Oasis by a limestone ridge.

The second cataract, known as the "Batn el Haggar," has a length of 200 kilometers and drop of 66 meters with the rapids of Amâra, Dâl, Semna, and Abka. At Semna are the rocks where Lepsius discovered the Nile gauges cut by one of the Pharoahs some 4,000 years ago. The Nile flood then was 8 meters higher at this spot than what it is to-day. The erosion which has taken place here is very excessive compared with that between the second and first cataracts and at the first cataract. At Wady Halfa, near the foot of the second cataract,

a masonry gauge, divided into meters, has been erected and read since 1877. Between the first and second cataracts the Nile has a length of 350 kilometers and slope of 1 : 12,500. The mean width of the river is 500 meters, and the mean depths in flood and summer are 9 and 2 meters. The velocity in summer falls to 50 centimeters per second and rises to 2 meters per second in flood. The river in this reach is generally within sandstone, and the greater part is provided with gigantic spurs on both banks. These spurs perform the double work of collecting soil on the sides in flood and training the river in summer. They were probably put up by the great Rameses 3,000 years ago, as some of the most massive of them have evidently been constructed to turn the river on a curve out of its natural channel on to the opposite side in order to secure deep water in front of the temple of Jerf Husain ("Jerf" means steep, scoured bank). The spurs have been constructed with care, and, as the courses of roughly dressed stone can be examined at fairly low water (I have never seen them at absolutely low water), it is evident that there has been no great degradation of the bed during the last 2,000 or 3,000 years. The first, or Assuân, cataract has a drop of 5 meters on a length of 5 kilometers.

From Khartoum to Assuân, on a total length of 1,809 kilometers, there are 563 kilometers of so-called cataracts with a total drop of 203 meters, and 1,246 kilometers of ordinary channel with a total drop of 83 meters

At the foot of the first cataract, opposite the town of Assuân, on the island of Elephantine, has stood a Nile gauge from very ancient times. An officer belonging to the Roman garrison in the time of the Emperor Severus, marked an extraordinary high flood on the gauge. The maximum flood mark at the time of the visit of Napoleon's French savants was, however, 2.11 meters higher than the above As the middle of Severus reign was A. D. 200, and the visit of the French savants A. D. 1800, they concluded that the bed and banks of the Nile had risen 2.11 meters in 1,600 years, or 0.132 meters per 100 years. The new gauge, divided into cubits and twenty-fourths, was erected in 1869 and has been recorded daily since then (a cubit = 54 centimeters).

From Assuân to the Barrage the length of the river is 970 kilometers, and the slope 1: 12,900, while the mean fall of the valley is 1: 10,800; from the Barrages, at the head of the Delta proper, the distance to the sea down either branch is 236 kilometers, with the same slope as before. The mean width of the main Nile is 820 meters, and the mean depth in flood 8.5 meters. On the Rosetta branch the mean width is 500 meters and depth 8 meters, while the Damietta branch has a mean width of 350 meters and mean depth of 7.5 meters. The mean velocity in flood is between 1.50 and 1.1 meters per second. As

the Nile in these reaches is in soil, it is evident that a mean flood velocity of 1.50 meters per second scours out a channel whose width is ninety times its depth, while a velocity of over one meter per second has a width some fifty times its depth. The natural canals, which take off the river and never silt, have a mean velocity of some 70 centimeters per second while the proportion of width to depth is about 12 to 1. Artificial canals of this section do not silt if their velocities are 70 centimeters per second, while silting takes place as readily when the velocity is greater as when it is less than the above. In muddy streams, like the Nile in flood, certain velocities demand certain proportions of width to depth, and if these are not given to it they will make it for themselves by eating away the sides if they can, or by silting up and raising the bed if they can not eat away the sides.

On Rhoda Island opposite Cairo has stood a gauge from very ancient times. It has been frequently reconstructed. The present gauge was erected in A. D. 861. It is in cubits and half cubits on some very arbitrary scale. When the gauge was constructed a reading of 16 cubits on the gauge meant the lowest level at which flood irrigation could be insured everywhere. In 1887 the Egyptian Government called upon all the Inspectors of Irrigation to report on the minimum gauge for perfect flood irrigation, and they reported 20.5 cubits on the gauge. The difference between 16 and 20.5 cubits on the Rhoda Island gauge is 1.22 meters, and as 1,026 years had elapsed since the construction of the gauge, it meant a rise of 0.119 meters per one hundred years. This is slightly under the rise calculated at Assuân, but then the river is muddier at Assuân than at Cairo. The Rhoda Island gauge has been read since A. D. 641, with interruptions, and the following table gives the mean readings per century of maximum flood and minimum low supply:

| Year A. D. | Flood. | Low supply. | No. of years recorded. |
|---|---|---|---|
| | *Meters.* | *Meters.* | |
| 641- 700 | R. L., 17.45 | R. L., 11.48 | 62 |
| 700- 800 | 17.44 | 10.78 | 100 |
| 800- 900 | 17.68 | 11.52 | 100 |
| 900-1000 | 17.46 | 11.30 | 100 |
| 1000-1100 | 17.62 | 11.61 | 100 |
| 1100-1200 | 17.74 | 12.17 | 100 |
| 1200-1300 | 17.69 | 11.43 | 100 |
| 1300-1400 | 18.17 | 11.09 | 100 |
| 1400-1500 | 18.00 | 11.81 | 52 |
| 1500-1600 | 18.44 | 11.93 | 52 |
| 1600-1700 | 18.81 | 11.14 | 28 |
| 1700-1800 | 19.12 | 11.77 | 94 |
| 1800-1892 | 20.31 | 12.71 | 68 |

The low-level gauges have been vitiated during the last few years by regulation at the Barrages. As the flood and low-level gauges in the above list have no accord with one another they are probably incorrect, like all other ancient records in this country. Even in the

last twenty years the flood gauge has been twice incorrectly recorded. Napoleon's savants relate how it was incorrectly recorded in 1801.

At Assuân the Nile has a mean range of 7.90 meters between high and low supply, with a maximum of 9.80 meters and a minimum of 6.40 meters. The high supply varies between 15,000 and 6,600 cubic meters per second, with a mean of 10,300 cubic meters per second, while the low supply varies between 250 and 1,500 cubic meters per second, with a mean of 470 cubic meters per second. September is generally the highest month and May the lowest.

At Cairo the Nile has a mean range of 6.70 meters, with a maximum of 9.2 meters and a minimum of 4.90 meters. The high supply varies between 12,500 and 4,900 cubic meters per second, with a mean of 7,700 cubic meters per second, while the low supply varies between 1,300 and 170 cubic meters per second. October is the highest month and June the lowest.

The approximate areas of the catchment basins of the Nile and its tributaries are as follows:

| | Square kilometers. |
|---|---|
| 1. The White Nile at the Ripon Falls | 260,000 |
| 2. The White Nile between the Ripon and Fola Falls | 180,000 |
| 3. The White Nile between the Fola Falls and Gondokoro | 60,000 |
| 4. The White Nile between Gondokoro and the Saubat Junction | 190,000 |
| 5. The Gazelle River | 220,000 |
| 6. The Arab River | 340,000 |
| 7. The Saubat River | 180,000 |
| 8. The White Nile between the Saubat junction and Khartoum | 820,000 |
| 9. The Blue Nile | 310,000 |
| 10. The Atbara and Gaash | 240,000 |
| 11. Desert north of Khartoum | 910,000 |
| The Nile | 3,110,000 |

If we examine the plan and note the length of the different rivers and their slope, it will be evident that the Gazelle, Saubat, the Blue Nile, and the Atbara are the ruling factors in flood, while the White Nile is the ruling factor during the remainder of the year.

The rainfall about Lakes Victoria and Albert, and about Gondokoro and the upper halves of the Saubat, Blue Nile, and Atbara, may be taken as 2 meters per annum. In the eastern half of the Gazelle River, the lower half of the Saubat, and middle third of the Atbara, 1 meter per annum may be taken as the rainfall. The western half of the Gazelle River has probably 50 centimeters per annum, while the Arab River and tail portions of the White and Blue Nile, and the Atbara, can not have more than 25 centimeters per annum. From Berber northward there is a very scanty rainfall indeed, and the country is considered rainless. Applying these rainfalls to the catchment basins we obtain the total mean annual rainfall in the Nile Valley, as follows:

*Mean annual rainfall in the Nile Valley.*

| | Square kilometers. | | Meters. | | Cubic meters. |
|---|---|---|---|---|---|
| 1. | 260,000 | × | 1.5 | = | 390,000,000,000 |
| 2. | 130,000 | × | 2.0 | = | 260,000,000,000 |
| 3. | 60,000 | × | 2.0 | = | 120,000,000,000 |
| 4. | 190,000 | × | 1.5 | = | 285,000,000,000 |
| 5. | 220,000 | × | 0.75 | = | 165,000,000,000 |
| 6. | 340,000 | × | 0.25 | = | 85,000,000,000 |
| 7. | 130,000 | × | 2.00 | = | 260,000,000,000 |
| 8. | 320,000 | × | 0.30 | = | 96,000,000,000 |
| 9. | 310,000 | × | 1.70 | = | 527,000,000,000 |
| 10. | 240,000 | × | 1.40 | = | 336,000,000,000 |
| 11. | 910,000 | × | 0.12 | = | 109,000,000,000 |
| | 3,110,000 | | 0.84 | | 2,633,000,000,000 |

We have next to consider the times of rainfall. In the great lake regions the rainy season lasts from March to December, with a maximum in August. At Gondokoro the rains continue from April to November, with a maximum in August. In the valley of the Saubat the rainy season is from June to November, with a maximum in August. It rains from April to September in the valley of the Gazelle River. From July to September is the rainy season at Khartoum, and from July to August in Kordofan and Darfûr, In Abyssinia there are light rains in January and February and heavy rains from the middle of April to September, with a maximum in August. August is the center of heavy rainfall everywhere.

The time it takes the water to travel down the different lengths of the river may be found from discharge, velocity, and slope calculations, and from comparisons between the fluctuations of the Gondokoro, Khartoum, Assuân, and Cairo gauges. I calculate that it takes the water eight days to travel from Lake Victoria to Lake Albert and five days from Lake Albert to Gondokoro. There is not much difference between high and low supply in these reaches. It takes the water thirty-six days to traverse the distance between Gondokoro and Khartoum in low supply and twenty days in flood. Between Khartoum and Assuân the times are twenty-six days in low supply and ten days in flood. Between Assuân and Cairo we have twelve days in low supply and six days in flood, while between Cairo and the sea we have three days and two days, respectively. It takes eighty-four days for the water in low supply to reach the sea from Lake Victoria, while in flood it takes fifty-one days.

The Blue Nile traverses the distance between its sources and Khartoum in some seventeen days in low supply and seven days in flood. The Atbara takes five days in flood, and the Saubat can not take a much longer time.

Referring to the map and keeping all the above facts in mind, an average year in the Nile Basin may be thus described: The heavy

rains near Gondokoro begin in April and force down the green water of the swamp regions. About April 15 the White Nile at Gondokoro begins to rise, and by September 1 has reached its maximum. In this interval the discharge has risen from 550 cubic meters per second to 1,650 cubic meters per second. This rise is felt at Khartoum about May 20, and at Assuân about June 10. The green water announcing this rise is seen at Cairo about June 22. In an average year on May 20, the White Nile discharge of 300 cubic meters per second at Khartoum begins to increase, and goes on gradually increasing to September 15 or 20, when the maximum floods of the White Nile and Saubat reach Khartoum and attain a discharge of 5,000 cubic meters per second. The low-water discharge of the Blue Nile is 160 cubic meters per second, and about June 5 it begins to rise fairly quickly and reaches its ordinary maximum of 5,000 cubic meters per second by about August 25. Owing to the two floods rarely being contemporary the ordinary maximum flood of 8,000 cubic meters per second is generally on September 5. The red, muddy water of the Blue Nile reaches Assuân about July 15, and Cairo about July 25. Once the red water begins to appear the rise is rapid, for the Atbara is in flood shortly after the Blue Nile, and its flood waters rise with great rapidity. The Atbara would come down much earlier than it does were it not that a whole month is expended in saturating the desert and its own dry sandy bed. The Atbara flood begins in the early part of July and is at its highest about August 20, reaching an ordinary maximum of 3,400 cubic meters per second, and occasionally an extraordinary maximum of 4,900 cubic meters per second.

It is owing to the earliness of the Atbara high flood and the lateness of the White Nile high flood that the ordinary maximum discharge of the Nile at Assuân is only 10,300 cubic meters per second. This is generally on September 5. When the White Nile is weak the maximum at Assuân is reached before or on September 5; when the White Nile is strong the maximum is reached about September 20. An early maximum at Assuân is always followed by a low summer supply, while a late maximum is nearly always followed by a high summer supply. Only once has this rule been broken and that was in 1891, when there were two maximums, one on September 4 and another on the 27th. In this year there must have been an extraordinary fall of rain in Abyssinia in September, for the flood of September 27 was very muddy, while as a rule the river at Assuân is very muddy in August, less so in September, and very much less so in October, when the White Nile is the ruling factor in the supply of the river.

Appendix I contains discharge tables of the Khartoum, Assuân, and Cairo gauges. The zero is everywhere mean low-water level. Appendix II gives five daily gauges and discharges of the Nile at

Khartoum during flood. Appendix III gives five daily gauges and discharges of the Nile at Assuân throughout the year. Appendix IV gives five daily gauges and discharges of the Nile at Cairo.

If the White Nile happens to be in very heavy flood late in September, and the September rains in Abyssinia are also very heavy, an extraordinary flood passes Assuân at the end of September and is disastrous for Egypt. This happened in 1878. Appendices III and IV contain details of this flood, of the minimum flood-year, 1877, and the mean of the twenty years from 1873 to 1892.

At Assuân the Nile enters Egypt, and it now remains to consider it in its last 1,200 kilometers. The ordinary minimum discharge at Assuân is 470 cubic meters per second, and is reached about the end of May. The river rises slowly till about July 20, and then rapidly through August, reaching its maximum about September 5, and then falling very slowly through October and November. The tables in Appendix III give every detail of a maximum, minimum, and mean year. The deep perennial irrigation canals take water all the year round, but the flood irrigation canals are closed with earthern banks till August 15, and are then all opened. These flood canals, of which there are some forty-five, are capable of discharging 2,000 cubic meters per second in an ordinary year, and have an immediate effect on the discharge of the Nile. The channel of the Nile itself and its numerous branches and arms consume a considerable quantity of water; the perennial canals take 200 cubic meters per second, the direct irrigation from the Nile between Assuân and Cairo takes 100 cubic meters per second, and 100 cubic meters per second are lost by evaporation off the Nile. Owing to all these different causes there is the net result that from August 15 to October 1 the Nile is discharging 2,800 cubic meters per second less at Cairo than at Assuân. During October and November the flood canals are closed, and the basins which have been filled in August and September discharge back into the Nile, and from October 5 to November 15 the Nile at Cairo is discharging 1,000 cubic meters per second in excess of the discharge at Assuân. An examination of Appendices III and IV will show this very clearly.

The ordinary minimum discharge at Cairo is 370 cubic meters per second, and is attained on June 10; the river rises slowly through July, and fairly quickly in August, and reaches its ordinary maximum on October 1, when there is no irrigation in the basins and the discharge from the basins is just beginning. The ordinary maximum discharge at Cairo is about 7,700 cubic meters per second. Through October the Nile at Cairo is practically stationary, and falls rapidly in November.

North of Cairo are the heads of the perennial canals which irrigate the Delta proper. These canals, with their feeders lower down, dis-

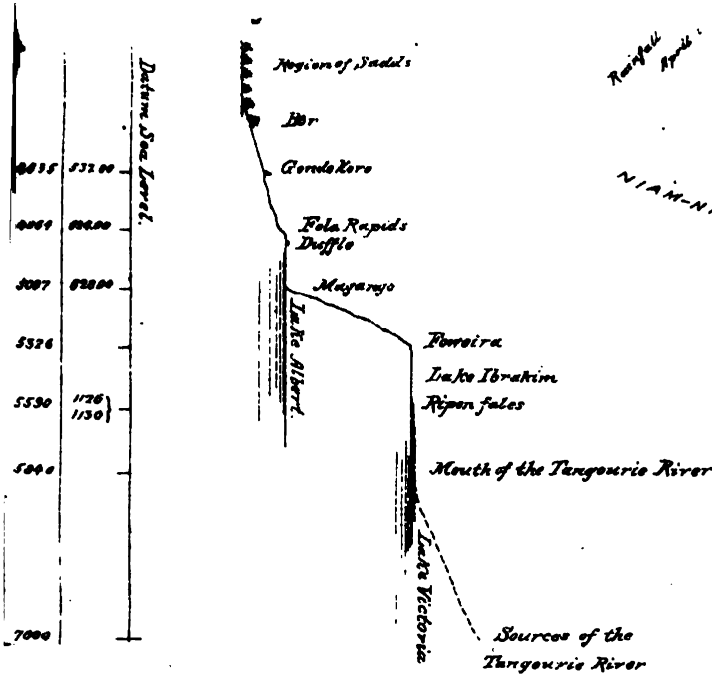
charge 1,200 cubic meters per second, and the ordinary maximum flood at Cairo of 7,700 cubic meters per second is reduced by this amount between Cairo and the sea. Of the 6,500 cubic meters per second which remain, 4,200 cubic meters per second find their way to the sea down the Rosetta branch and 2,300 cubic meters per second down the Damietta branch. During extraordinary floods the Damietta branch has discharged 4,300 cubic meters per second and the Rosetta branch 7,000 cubic meters per second.

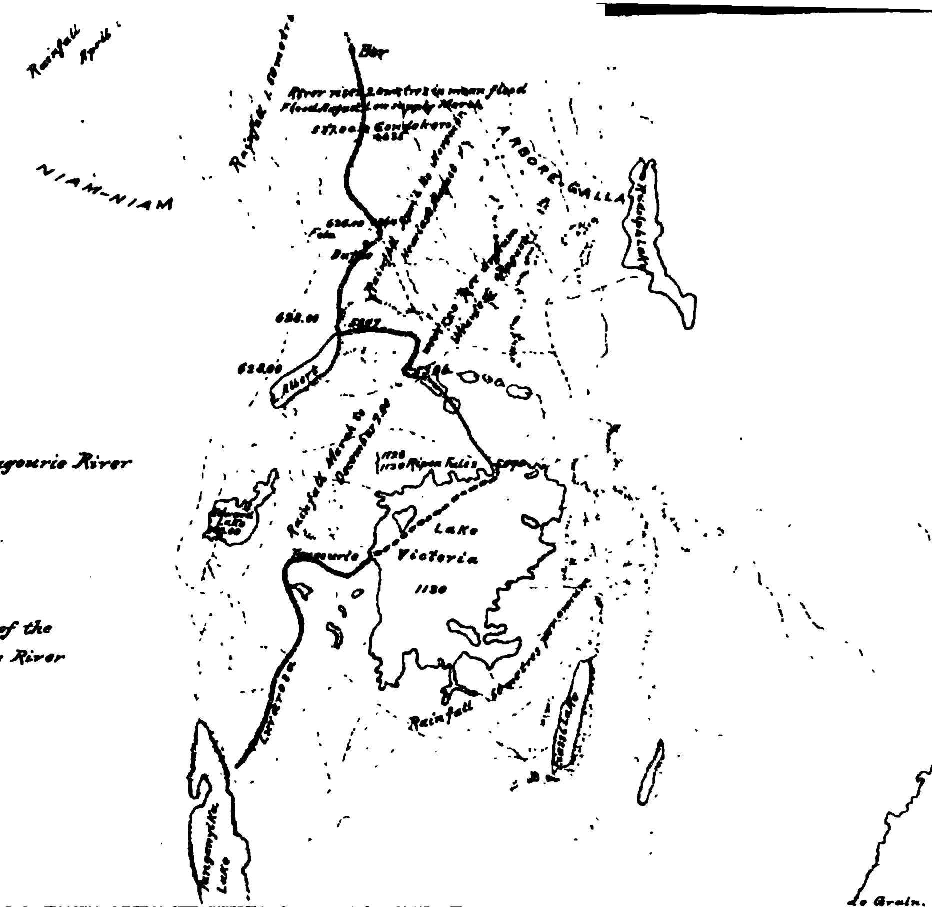
We have so far considered the Nile in flood, it now remains to quickly dispose of the low supply. After reaching its maximum, the Atbara, which is a torrential river, falls more rapidly than the others, and by the end of October has practically disappeared. After the middle of September the Blue Nile falls quickly, while the White Nile, with its large basin, gentle flow, and numerous reservoirs, falls very deliberately. The mean discharge of the White Nile at Gondokoro, in an ordinary year, at the time of low supply, is 550 cubic meters per second. By the time it reaches Khartoum it is reduced by evaporation to some 350 cubic meters per second. The ordinary low supply of the Blue Nile is 190 cubic meters per second, giving an ordinary low supply to the Nile at Khartoum of 540 cubic meters per second. The Atbara supplies nothing. Between Khartoum and Assuân there is a further loss from evaporation and irrigation of 70 cubic meters per second, and the ordinary low supply delivered at Assuân is 470 cubic meters per second. In very bad years the discharge at Assuân has fallen to 240 cubic meters per second, which would mean 310 cubic meters per second at Khartoum, probably; and, adopting Linant Pasha's proportion, the White Nile would be discharging 200 cubic meters per second and the Blue Nile 110 cubic meters per second. As the White Nile at Gondokoro never discharges much under 500 cubic meters per second, the loss on that river, under the most unfavorable conditions, is about 300 cubic meters per second, while the loss on the Blue Nile cannot be more than 50 cubic meters per second. Summing up, therefore, we may state that in a very bad summer the Nile sources supply 660 cubic meters per second, the discharge at Khartoum has dwindled to 310 cubic meters per second and at Assuân to 240 cubic meters per second. The moment the daily fall of the river becomes less than the daily loss by evaporation all the small ponds and pools cease to aid the stream, and if they are very extensive, as they are south of Fashoda, they diminish the discharge considerably by their large evaporating areas. The six cataracts of the Nile, with their numerous raised sills, moderate the floods and lengthen them out, but when the two months of real low discharge have come the great reservoirs of the Nile are the sole sources of supply.

As Egypt possesses no barometric, thermometric, or rain-gauge

stations in the valley of the Nile, we are always ignorant of the coming flood, though famine years in India are generally years of low flood in Egypt. If, however, the summer supply of the Nile has been exceedingly low and exceedingly late, we anticipate a high flood following it, as the drought in the valley of the White Nile must create a powerful draught on to the Indian Ocean. Again, as to the summer supply, we generally anticipate a poor volume in the river at that season if the Nile flood at Assuân is an early one, and a good supply if the Nile flood at Assuân is a late one. Appendix V, which contains numerous statistics of times and proportions of flood and low supply for the twenty years from 1873 to 1892, fully bears out this statement. Between Assuân and Cairo, previous to 1890, we had little control over the flood, as the canals and escapes in upper Egypt had no masonry-regulating works, and the Nile in high flood did very much what it liked. Since 1890, however, the Public Works Department has constructed ninety important regulating works, and by proper manipulation we can now fairly control a high flood by using the canals and escapes so as not to let the Nile at Cairo rise above 8 meters, which is the maximum gauge the banks on the Rosetta and Damietta branches can support with any degree of security. It was mainly owing to this power of control that the excessive flood of 1892 passed through Egypt without causing any real damage. The Egyptian Government to-day is very seriously considering the question of flood control and increase of summer supply, and we hope to find a solution for the former by escaping excess flood water into some of the depressions which border the Nile Valley, and a solution for the latter by the creation of reservoirs either in the deserts and the channel of the Nile itself north of Wady Halfa, or by regulating works at the sources of the rivers themselves, or perhaps by a combination of both.

When we consider the energy and the self-denying labors of the men who achieved the great discoveries of the sources of the Nile, it seems but a poor compensation to them to know that these sources can now be depicted on the plans. It would be a triumph indeed, and a real compensation, if the resources of modern science could be employed to utilize these great lakes, and by the construction of suitable works to insure a constant and plentiful supply of water to the Nile Valley during the summer months when water is scarce and as valuable as gold. Both the Victoria and the Albert lakes lend themselves to be utilized as reservoirs as they have rocky sills at their outlets, while the Albert and Tsana lakes, by their convenient size, are eminently suited for regulating basins. The day these works are carried out at the sources of the Nile the lakes will take their proper place in the economy of the water supply, and we shall be able to say of them in their entirety, as we can say of them to-day in their degree,




LONGITUDINAL SECTION OF THE NILE.

Horizontal scale $= 1 : 10{,}000{,}000$.
Vertical scale $= 1 : 10{,}000$.

that what the snows of the Alps are to the Po, lakes Victoria, Nyanza, and Tsana are to the Nile, and what the Italian lakes are to the plains of Lombardy, Lake Albert is to the land of Egypt.

## APPENDICES.

### I.—Discharge Tables for the Khartoum, Assuan, and Cairo Gauges.

The discharges opposite the gauges are mean discharges. On a rising Nile the discharges are in excess of those in the table, and on a falling Nile they are under them. This will be noticed in Appendices III and IV.

The site chosen for taking the discharges of a river throughout the year should be such that the bed of the river at the site would be dry if the discharge fell to zero. Deep, scoured-out sections of a river may give fairly accurate discharges in high flood, but they give very inaccurate discharges in low supply, as the action which causes the scour exists only in flood.

The following discharges have been calculated from observed surface velocities on Harlacher's method (using 0.85 as the reducing constant), and from Manning's formula and surface slope observations (using 33 as the constant):

*Approximate discharge table for the Khartoum gauge.*

[The zero of the gauge is mean low-water level or R. L. 384.00, or 6.30 meters on the gauge which used to stand in front of old Government house at Khartoum. Gauges in meters; discharges in cubic meters per second.]

| Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. |
|---|---|---|---|---|---|---|---|
| 1.5 | 1,460 | 3.1 | 2,700 | 4.7 | 4,000 | 6.3 | 7,420 |
| .6 | 1,530 | .2 | 2,750 | .8 | 4,180 | .4 | 7,690 |
| .7 | 1,600 | .3 | 2,800 | .9 | 4,360 | .5 | 7,960 |
| .8 | 1,690 | .4 | 2,850 | 5.0 | 4,540 | .6 | 8,230 |
| .9 | 1,780 | .5 | 2,900 | .1 | 4,720 | .7 | 8,500 |
| 2.0 | 1,870 | .6 | 2,950 | .2 | 4,900 | .8 | 8,900 |
| .1 | 1,960 | .7 | 3,000 | .3 | 5,080 | .9 | 9,300 |
| .2 | 2,050 | .8 | 3,100 | .4 | 5,260 | 7.0 | 9,700 |
| .3 | 2,140 | .9 | 3,200 | .5 | 5,440 | .1 | 10,100 |
| .4 | 2,230 | 4.0 | 3,300 | .6 | 5,620 | .2 | 10,500 |
| .5 | 2,320 | .1 | 3,400 | .7 | 5,800 | .3 | 10,900 |
| .6 | 2,410 | .2 | 3,500 | .8 | 6,070 | .4 | 11,300 |
| .7 | 2,500 | .3 | 3,600 | .9 | 6,340 | .5 | 11,700 |
| .8 | 2,550 | .4 | 3,700 | 6.0 | 6,610 | .6 | 12,100 |
| .9 | 2,600 | .5 | 3,800 | .1 | 6,880 | .7 | 12,500 |
| 3.0 | 2,650 | .6 | 3,900 | .2 | 7,150 | .8 | 12,900 |

*Discharge table for the Assuân gauge.*

[Zero on the gauge is mean low-water level or R. L. 85.00. Gauges in meters; discharges in cubic meters per second.]

| Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. |
|---|---|---|---|---|---|---|---|
| −2.00 | 0 | −1.20 | 110 | − .40 | 330 | 0.40 | 650 |
| −1.90 | 5 | −1.10 | 130 | − .30 | 360 | .50 | 700 |
| −1.80 | 10 | −1.00 | 150 | − .20 | 400 | .60 | 750 |
| −1.70 | 20 | − .90 | 180 | − .10 | 440 | .70 | 800 |
| −1.60 | 30 | − .80 | 210 | 0.00 | 470 | .80 | 850 |
| −1.50 | 50 | − .70 | 240 | .10 | 510 | 0.90 | 900 |
| −1.40 | 70 | − .60 | 270 | .20 | 550 | 1.00 | 950 |
| −1.30 | 90 | − .50 | 300 | .30 | 600 | .10 | 1,010 |

*Discharge table for the Assuân gauge*—Continued.

| Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. |
|---|---|---|---|---|---|---|---|
| 1.20 | 1,070 | 3.30 | 2,610 | 5.40 | 4,860 | 7.50 | 9,000 |
| .30 | 1,130 | .40 | 2,700 | .50 | 5,000 | .60 | 9,320 |
| .40 | 1,190 | .50 | 2,790 | .60 | 5,140 | .70 | 9,640 |
| .50 | 1,250 | .60 | 2,880 | .70 | 5,280 | .80 | 9,960 |
| .60 | 1,310 | .70 | 2,970 | .80 | 5,420 | .90 | 10,280 |
| .70 | 1,370 | .80 | 3,060 | .90 | 5,560 | 8.00 | 10,600 |
| .80 | 1,430 | .90 | 3,150 | 6.00 | 5,800 | .10 | 11,020 |
| .90 | 1,490 | 4.00 | 3,240 | .10 | 6,000 | .20 | 11,440 |
| 2.00 | 1,550 | .10 | 3,356 | .20 | 6,200 | .30 | 11,860 |
| .10 | 1,610 | .20 | 3,472 | .30 | 6,400 | .40 | 12,280 |
| .20 | 1,670 | .30 | 3,588 | .40 | 6,600 | .50 | 12,700 |
| .30 | 1,750 | .40 | 3,704 | .50 | 6,800 | .60 | 13,120 |
| .40 | 1,830 | .50 | 3,820 | .60 | 7,000 | .70 | 13,540 |
| .50 | 1,910 | .60 | 3,936 | .70 | 7,200 | .80 | 13,960 |
| .60 | 1,990 | .70 | 4,052 | .80 | 7,400 | .90 | 14,380 |
| .70 | 2,070 | .80 | 4,168 | .90 | 7,600 | 9.00 | 14,800 |
| .80 | 2,160 | .90 | 4,284 | 7.00 | 7,800 | .10 | 15,220 |
| .90 | 2,250 | 5.00 | 4,400 | .10 | 8,040 | .20 | 15,640 |
| 3.00 | 2,340 | .10 | 4,540 | .20 | 8,280 | | |
| .10 | 2,430 | .20 | 4,680 | .30 | 8,520 | | |
| .20 | 2,520 | .30 | 4,720 | .40 | 8,760 | | |

*Discharge table for the Cairo gauge.*

[Gauges in meters. Discharge in cubic meters per second. Zero on the gauge is mean low-water level or R. L. 12.70. Regulation at the Barrages vitiates the discharges below 1.60 at the present time.]

| Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. |
|---|---|---|---|---|---|---|---|
| —1.20 | 0 | 1.30 | 1,200 | 3.80 | 3,750 | 6.30 | 6,800 |
| —1.10 | 15 | .40 | 1,290 | .90 | 3,860 | .40 | 7,050 |
| —1.00 | 30 | .50 | 1,380 | 4.00 | 3,970 | .50 | 7,300 |
| — .90 | 60 | .60 | 1,470 | .10 | 4,080 | .60 | 7,550 |
| — .80 | 90 | .70 | 1,560 | .20 | 4,190 | .70 | 7,800 |
| — .70 | 120 | .80 | 1,650 | .30 | 4,300 | .80 | 8,050 |
| — .60 | 150 | .90 | 1,740 | .40 | 4,410 | .90 | 8,300 |
| — .50 | 180 | 2.00 | 1,830 | .50 | 4,520 | 7.00 | 8,550 |
| — .40 | 220 | .10 | 1,920 | .60 | 4,630 | .10 | 8,800 |
| — .30 | 260 | .20 | 2,010 | .70 | 4,740 | .20 | 9,050 |
| — .20 | 300 | .30 | 2,100 | .80 | 4,850 | .30 | 9,300 |
| — .10 | 340 | .40 | 2,210 | .90 | 4,960 | .40 | 9,570 |
| 0.00 | 380 | .50 | 2,320 | 5.00 | 5,070 | .50 | 9,840 |
| .10 | 420 | .60 | 2,430 | .10 | 5,180 | .60 | 10,110 |
| .20 | 460 | .70 | 2,540 | .20 | 5,290 | .70 | 10,380 |
| .30 | 500 | .80 | 2,650 | .30 | 5,400 | .80 | 10,650 |
| .40 | 570 | .90 | 2,760 | .40 | 5,540 | .90 | 10,920 |
| .50 | 640 | 3.00 | 2,870 | .50 | 5,680 | 8.00 | 11,190 |
| .60 | 710 | .10 | 2,980 | .60 | 5,820 | .10 | 11,460 |
| .70 | 780 | .20 | 3,090 | .70 | 5,960 | .20 | 11,730 |
| .80 | 850 | .30 | 3,200 | .80 | 6,100 | .30 | 12,000 |
| .90 | 920 | .40 | 3,310 | .90 | 6,240 | .40 | 12,270 |
| 1.00 | 990 | .50 | 3,420 | 6.00 | 6,380 | .50 | 12,540 |
| .10 | 1,060 | .60 | 3,530 | .10 | 6,520 | .60 | 12,810 |
| .20 | 1,130 | .70 | 3,640 | .20 | 6,660 | | |

## II.—KHARTOUM.

Five daily gauges and discharges for the maximum, minimum, and mean years, from 1873 to 1882, during flood.

Zero on the gauge is mean low-water level, R. L. 384.00 meters, or 6.30 meters on the old gauge at Khartoum, on the Blue Nile.

*Gauges in meters and discharges in cubic meters per second of the Nile at Khartoum for the maximum, minimum, and mean years between* 1873 *and* 1882.

[Zero on the gauge is mean low-water level.]

| Date. | Maximum, 1878. | | Minimum, 1877. | | Mean of 10 years. | |
|---|---|---|---|---|---|---|
| | Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. |
| June 15 | 2.00 | 1,870 | 1.90 | 1,780 | 1.70 | 1,600 |
| 20 | 2.00 | 1,870 | 2.10 | 1,960 | 1.85 | 1,780 |
| 25 | 2.45 | 2,320 | 2.45 | 2,320 | 2.25 | 2,140 |
| July 1 | 2.80 | 2,550 | 3.00 | 2,650 | 2.65 | 2,500 |
| 5 | 2.80 | 2,550 | 2.90 | 2,600 | 2.65 | 2,600 |
| 10 | 3.20 | 2,750 | 3.55 | 2,950 | 3.30 | 2,800 |
| 15 | 3.70 | 3,000 | 3.80 | 3,100 | 3.60 | 2,950 |
| 20 | 4.30 | 3,600 | 4.30 | 3,600 | 4.10 | 3,400 |
| 25 | 4.40 | 3,700 | 4.30 | 3,600 | 4.60 | 3,900 |
| Aug. 1 | 4.60 | 3,900 | 4.95 | 4,360 | 5.25 | 5,080 |
| 5 | 5.60 | 5,620 | 4.60 | 3,900 | 5.60 | 5,620 |
| 10 | 6.05 | 6,880 | 5.20 | 4,900 | 5.95 | 6,610 |
| 15 | 6.40 | 7,690 | 5.15 | 4,800 | 6.15 | 7,000 |
| 20 | 6.20 | 7,150 | 5.10 | 4,720 | 6.15 | 7,150 |
| 25 | 6.10 | 6,880 | 5.55 | 5,150 | 6.35 | 7,600 |
| Sept. 1 | 6.80 | 8,900 | 5.20 | 4,900 | 6.50 | 7,960 |
| 5 | 7.10 | 10,100 | 5.10 | 4,720 | 6.45 | 7,800 |
| 10 | 7.30 | 10,900 | 5.20 | 4,900 | 6.66 | 8,100 |
| 15 | 7.50 | 11,700 | 5.30 | 5,080 | 6.50 | 7,960 |
| 20 | 7.80 | 12,900 | 5.20 | 4,900 | 6.50 | 7,960 |
| 25 | 7.60 | 12,100 | 4.95 | 4,360 | 6.30 | 7,420 |
| Oct. 1 | 7.40 | 11,300 | 4.50 | 3,800 | 5.90 | 6,340 |
| 5 | 7.05 | 9,700 | 4.40 | 3,700 | 5.70 | 5,800 |
| 10 | 6.75 | 8,500 | 4.20 | 3,500 | 5.50 | 5,440 |
| 15 | 6.40 | 7,690 | 4.10 | 3,400 | 5.15 | 4,720 |
| June 15 to July 15 | 2.70 | 2,410 | 2.80 | 2,490 | 2.60 | 2,350 |
| July 15 to August 15 | 5.00 | 4,840 | 4.65 | 4,050 | 5.10 | 4,930 |
| August 15 to September 15 | 6.75 | 8,940 | 5.20 | 4,890 | 6.40 | 7,680 |
| September 15 to October 15 | 7.25 | 10,700 | 4.65 | 4,080 | 5.90 | 6,550 |

## III.—Assuan.

Five daily gauges and discharges for the maximum, minimum, and mean years from 1873 to 1892.

Mean monthly and yearly discharges for the maximum, minimum, and mean years from 1873 to 1892.

Zero on the gauge is mean low-water level, *i. e.*, R. L. 85.00 meters above sea level.

*Gauges in meters and discharges in cubic meters per second for the maximum, minimum, and mean years between* 1873 *and* 1892.

[Zero on the gauge is mean low-water level.]

| Date. | Maximum, 1878-'79. | | Minimum, 1877-'78. | | Mean of 20 years. | |
|---|---|---|---|---|---|---|
| | Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. |
| June 1 | —.66 | 240 | .19 | 550 | .06 | 480 |
| 5 | —.68 | 240 | .28 | 600 | .10 | 510 |
| 10 | —.68 | 240 | .46 | 700 | .10 | 510 |
| 15 | —.66 | 240 | .91 | 900 | .36 | 650 |
| 20 | —.59 | 270 | 1.09 | 1,010 | .49 | 700 |
| 25 | —.32 | 360 | 1.07 | 1,000 | .72 | 850 |
| July 1 | .67 | 800 | 1.30 | 1,130 | 1.12 | 1,010 |
| 5 | .94 | 950 | 1.81 | 1,490 | 1.39 | 1,190 |
| 10 | 1.05 | 1,010 | 2.13 | 1,670 | 1.82 | 1,450 |
| 15 | 1.44 | 1,250 | 3.23 | 2,610 | 2.25 | 1,700 |
| 20 | 2.47 | 1,910 | 3.23 | 2,610 | 2.87 | 2,250 |
| 25 | 3.82 | 3,150 | 3.70 | 2,970 | 3.71 | 3,060 |
| Aug. 1 | 5.39 | 4,860 | 4.72 | 4,170 | 5.16 | 4,680 |
| 5 | 5.62 | 5,280 | 4.78 | 4,170 | 5.71 | 5,420 |
| 10 | 6.25 | 6,400 | 5.35 | 4,860 | 6.59 | 7,000 |

*Gauges in meters and discharges in cubic meters per second, etc.*—Continued.

| Date. | Maximum, 1878–'79. | | Minimum, 1877–'78. | | Mean of 20 years. | |
|---|---|---|---|---|---|---|
| | Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. |
| Aug. 15 | 7.17 | 8,280 | 5.75 | 5,420 | 7.04 | 8,040 |
| 20 | 7.48 | 9,000 | 6.40 | 6,600 | 7.34 | 8,760 |
| 25 | 8.07 | 11,020 | 6.13 | 6,000 | 7.62 | 9,400 |
| Sept. 1 | 7.60 | 9,320 | 6.18 | 6,200 | 7.85 | 10,280 |
| 5 | 8.14 | 11,440 | 6.27 | 6,300 | 7.98 | 10,280 |
| 10 | 8.52 | 13,120 | 6.09 | 5,800 | 7.92 | 10,280 |
| 15 | 8.90 | 14,380 | 6.02 | 5,800 | 7.87 | 9,960 |
| 20 | 8.86 | 13,960 | 5.95 | 5,560 | 7.72 | 9,640 |
| 25 | 9.00 | 14,800 | 6.27 | 6,400 | 7.62 | 9,320 |
| Oct. 1 | 9.15 | 15,220 | 6.04 | 5,800 | 7.30 | 8,520 |
| 5 | 8.92 | 14,380 | 5.64 | 5,140 | 7.00 | 7,800 |
| 10 | 8.47 | 12,280 | 5.21 | 4,680 | 6.65 | 7,000 |
| 15 | 7.91 | 10,280 | 4.92 | 4,280 | 6.32 | 6,400 |
| 20 | 7.60 | 9,320 | 4.63 | 3,940 | 5.98 | 5,560 |
| 25 | 7.42 | 8,760 | 4.54 | 3,820 | 5.65 | 5,140 |
| Nov. 1 | 6.72 | 7,200 | 3.88 | 3,060 | 5.11 | 4,540 |
| 5 | 6.34 | 6,400 | 3.73 | 2,970 | 4.83 | 4,170 |
| 10 | 5.86 | 5,420 | 3.61 | 2,880 | 4.51 | 3,820 |
| 15 | 5.50 | 5,000 | 3.41 | 2,700 | 4.23 | 3,472 |
| 20 | 5.17 | 4,540 | 3.23 | 2,520 | 4.00 | 3,240 |
| 25 | 4.92 | 4,280 | 2.94 | 2,250 | 3.76 | 2,970 |
| Dec. 1 | 4.67 | 3,940 | 2.60 | 1,990 | 3.51 | 2,790 |
| 5 | 4.54 | 3,820 | 2.51 | 1,910 | 3.38 | 2,610 |
| 10 | 4.38 | 3,590 | 2.40 | 1,830 | 3.24 | 2,520 |
| 15 | 4.20 | 3,470 | 2.22 | 1,670 | 3.08 | 2,340 |
| 20 | 4.09 | 3,360 | 2.13 | 1,610 | 2.96 | 2,250 |
| 25 | 3.93 | 3,150 | 1.95 | 1,490 | 2.85 | 2,160 |
| Jan. 1 | 3.70 | 2,970 | 1.97 | 1,490 | 2.64 | 1,990 |
| 5 | 3.59 | 2,880 | 1.88 | 1,490 | 2.55 | 1,910 |
| 10 | 3.52 | 2,790 | 1.75 | 1,370 | 2.45 | 1,830 |
| 15 | 3.41 | 2,700 | 1.61 | 1,310 | 2.33 | 1,750 |
| 20 | 3.28 | 2,520 | 1.48 | 1,190 | 2.22 | 1,670 |
| 25 | 3.20 | 2,520 | 1.39 | 1,130 | 2.11 | 1,610 |
| Feb. 1 | 3.12 | 2,430 | 1.21 | 1,070 | 1.95 | 1,490 |
| 5 | 3.05 | 2,340 | 1.07 | 950 | 1.86 | 1,430 |
| 10 | 2.96 | 2,250 | .91 | 900 | 1.74 | 1,370 |
| 15 | 2.89 | 2,160 | .80 | 850 | 1.61 | 1,310 |
| 20 | 2.83 | 2,160 | .67 | 800 | 1.48 | 1,190 |
| 25 | 2.78 | 2,070 | .51 | 700 | 1.39 | 1,130 |
| Mar. 1 | 2.74 | 2,070 | .44 | 650 | 1.28 | 1,070 |
| 5 | 2.71 | 2,070 | .33 | 600 | 1.19 | 1,050 |
| 10 | 2.67 | 1,990 | .24 | 550 | 1.08 | 1,000 |
| 15 | 2.60 | 1,990 | .17 | 520 | .98 | 930 |
| 20 | 2.58 | 1,910 | .08 | 500 | .87 | 870 |
| 25 | 2.51 | 1,910 | 0.00 | 470 | .76 | 820 |
| April 1 | 2.44 | 1,830 | —.10 | 440 | .61 | 750 |
| 5 | 2.38 | 1,800 | —.12 | 400 | .53 | 700 |
| 10 | 2.31 | 1,750 | —.19 | 400 | .44 | 650 |
| 15 | 2.22 | 1,670 | —.26 | 360 | .37 | 620 |
| 20 | 2.17 | 1,650 | —.28 | 360 | .31 | 600 |
| 25 | 2.26 | 1,700 | —.37 | 330 | .26 | 580 |
| May 1 | 2.24 | 1,700 | —.41 | 330 | .18 | 540 |
| 5 | 2.20 | 1,670 | —.48 | 300 | .15 | 530 |
| 10 | 2.02 | 1,550 | —.50 | 300 | .09 | 500 |
| 15 | 1.95 | 1,490 | —.50 | 300 | .08 | 490 |
| 20 | 1.90 | 1,490 | —.57 | 270 | .04 | 480 |
| 25 | 2.00 | 1,550 | —.64 | 270 | 0.00 | 470 |
| 31 | 2.17 | 1,670 | —.66 | 260 | .05 | 490 |
| **Month.** | | | | | | |
| June | —.49 | 320 | .76 | 840 | .39 | 660 |
| July | 2.12 | 1,850 | 2.85 | 1,670 | 2.53 | 2,080 |
| August | 6.85 | 7,840 | 5.64 | 5,370 | 6.80 | 7,850 |
| September | 8.63 | 13,330 | 6.12 | 5,940 | 7.77 | 9,810 |
| October | 8.04 | 11,040 | 4.98 | 4,420 | 6.30 | 6,400 |
| November | 5.58 | 5,120 | 3.36 | 2,640 | 4.37 | 3,550 |
| December | 4.22 | 3,470 | 2.25 | 1,710 | 3.10 | 2,380 |
| January | 3.40 | 2,680 | 1.62 | 1,280 | 2.33 | 1,750 |
| February | 2.91 | 2,200 | .80 | 840 | 1.62 | 1,280 |
| March | 2.61 | 1,970 | .16 | 530 | .97 | 920 |
| April | 2.28 | 1,720 | —.24 | 380 | .39 | 630 |
| May | 2.04 | 1,580 | —.51 | 290 | .08 | 500 |
| Mean of the year | 4.02 | 4,430 | 2.32 | 2,160 | 3.05 | 3,150 |

## IV.—Cairo.

Five daily gauges and discharges for the maximum, minimum, and mean years between 1873 and 1892.

Mean monthly and yearly discharges for the maximum, minimum, and mean years from 1873 to 1892.

Zero on the gauge is mean low-water level, *i. e.*, R. L. 12.70 meters above sea level.

*Gauges in meters and discharges in cubic meters per second for the maximum, minimum, and mean years between* 1873 *and* 1892.

[Zero on the gauge is mean low-water level.]

| Date. | | Maximum, 1878-'79. | | Minimum, 1877-'78. | | Mean of 20 years. | |
|---|---|---|---|---|---|---|---|
| | | Gauge. | Discharge. | Gauge. | Discharge. | Gauge. | Discharge. |
| June | 1 | — .42 | 180 | .28 | 450 | .49 | 380 |
| | 5 | — .48 | 180 | .17 | 430 | .46 | 370 |
| | 10 | — .55 | 180 | .15 | 430 | .44 | 370 |
| | 15 | — .57 | 170 | .17 | 430 | .42 | 370 |
| | 20 | — .62 | 170 | .21 | 440 | .47 | 420 |
| | 25 | — .69 | 170 | .48 | 600 | .52 | 420 |
| July | 1 | — .64 | 170 | .73 | 700 | .61 | 500 |
| | 5 | — .60 | 170 | .70 | 700 | .69 | 550 |
| | 10 | — .10 | 300 | .75 | 800 | .88 | 700 |
| | 15 | .33 | 500 | .90 | 900 | 1.08 | 900 |
| | 20 | .52 | 600 | 1.12 | 1,010 | 1.35 | 1,200 |
| | 25 | .97 | 950 | 1.91 | 1,830 | 1.74 | 1,700 |
| Aug. | 1 | 2.54 | 2,430 | 2.38 | 2,210 | 2.64 | 2,430 |
| | 5 | 3.66 | 3,640 | 3.19 | 3,090 | 3.61 | 3,640 |
| | 10 | 4.40 | 4,410 | 3.75 | 3,760 | 4.47 | 4,520 |
| | 15 | 4.90 | 4,960 | 4.08 | 4,080 | 5.24 | 5,400 |
| | 20 | 5.73 | 6,100 | 4.15 | 4,190 | 5.47 | 5,680 |
| | 25 | 5.85 | 6,240 | 4.88 | 4,900 | 5.70 | 5,960 |
| Sept. | 1 | 6.16 | 6,660 | 4.81 | 4,850 | 5.94 | 6,038 |
| | 5 | 6.08 | 6,380 | 4.78 | 4,740 | 6.07 | 6,520 |
| | 10 | 6.38 | 7,050 | 4.83 | 4,850 | 6.23 | 6,800 |
| | 15 | 6.72 | 8,050 | 4.75 | 4,800 | 6.33 | 7,050 |
| | 20 | 7.23 | 9,100 | 4.74 | 4,800 | 6.47 | 7,300 |
| | 25 | 7.52 | 10,000 | 4.63 | 4,630 | 6.56 | 7,550 |
| Oct. | 1 | 7.98 | 11,190 | 4.80 | 4,850 | 6.63 | 7,650 |
| | 5 | 8.07 | 11,460 | 4.74 | 4,740 | 6.57 | 7,300 |
| | 10 | 8.54 | 12,540 | 4.59 | 4,520 | 6.47 | 7,100 |
| | 15 | 8.25 | 11,730 | 4.40 | 4,410 | 6.43 | 7,050 |
| | 20 | 8.11 | 11,460 | 4.11 | 4,000 | 6.31 | 6,800 |
| | 25 | 7.80 | 10,650 | 3.91 | 3,860 | 6.20 | 6,660 |
| Nov. | 1 | 7.33 | 9,300 | 3.68 | 3,530 | 5.65 | 5,820 |
| | 5 | 7.10 | 8,800 | 3.43 | 3,310 | 5.15 | 5,200 |
| | 10 | 6.96 | 8,300 | 3.15 | 2,980 | 4.62 | 4,630 |
| | 15 | 6.45 | 7,050 | 3.26 | 3,090 | 4.20 | 4,190 |
| | 20 | 5.70 | 5,960 | 3.21 | 3,090 | 3.84 | 3,750 |
| | 25 | 5.06 | 5,070 | 3.02 | 2,870 | 3.54 | 3,420 |
| Dec. | 1 | 4.63 | 4,630 | 2.64 | 2,430 | 3.30 | 3,200 |
| | 5 | 4.45 | 4,410 | 2.48 | 2,210 | 3.15 | 3,000 |
| | 10 | 4.24 | 4,190 | 2.26 | 2,010 | 2.98 | 2,800 |
| | 15 | 4.04 | 3,970 | 2.15 | 1,920 | 2.84 | 2,650 |
| | 20 | 3.91 | 3,860 | 2.03 | 1,830 | 2.71 | 2,540 |
| | 25 | 3.79 | 3,700 | 1.91 | 1,740 | 2.58 | 2,400 |
| Jan. | 1 | 3.50 | 3,420 | 1.82 | 1,650 | 2.43 | 2,210 |
| | 5 | 3.35 | 3,200 | 1.75 | 1,560 | 2.34 | 2,150 |
| | 10 | 3.19 | 3,000 | 1.69 | 1,470 | 2.24 | 2,050 |
| | 15 | 2.96 | 2,800 | 1.60 | 1,470 | 2.14 | 1,950 |
| | 20 | 2.91 | 2,760 | 1.46 | 1,290 | 2.05 | 1,880 |
| | 25 | 2.81 | 2,650 | 1.33 | 1,200 | 1.94 | 1,780 |
| Feb. | 1 | 2.68 | 2,450 | 1.20 | 1,130 | 1.83 | 1,550 |
| | 5 | 2.64 | 2,450 | 1.12 | 1,060 | 1.79 | 1,510 |
| | 10 | 2.56 | 2,400 | 1.01 | 990 | 1.71 | 1,390 |
| | 15 | 2.46 | 2,210 | .88 | 850 | 1.65 | 1,390 |
| | 20 | 2.40 | 2,210 | .75 | 780 | 1.57 | 1,270 |
| | 25 | 2.34 | 2,100 | .66 | 710 | 1.49 | 1,200 |
| Mar. | 1 | 2.32 | 2,100 | .59 | 640 | 1.45 | 1,100 |
| | 5 | 2.28 | 2,010 | .52 | 640 | 1.39 | 1,050 |
| | 10 | 2.21 | 2,010 | .44 | 570 | 1.32 | 980 |
| | 15 | 2.17 | 1,920 | .46 | 500 | 1.28 | 960 |
| | 20 | 2.13 | 1,920 | .50 | 470 | 1.22 | 900 |
| | 25 | 2.09 | 1,850 | .39 | 420 | 1.15 | 800 |

*Gauges in meters and discharges in cubic meters per second, etc.*—Continued.

| Date. | Maximum, 1878-'79. | | Minimum, 1877-'78. | | Mean of 20 years. | |
|---|---|---|---|---|---|---|
| | Gauge. | Discharge. | Gauge. | Discharge | Gauge. | Discharge. |
| Apr. 1 | 2.05 | 1,850 | .28 | 400 | 1.05 | 750 |
| 5 | 2.01 | 1,830 | .19 | 380 | 1.00 | 720 |
| 10 | 1.98 | 1,740 | .17 | 360 | .93 | 650 |
| 15 | 1.96 | 1,740 | .06 | 330 | .87 | 600 |
| 20 | 1.91 | 1,740 | .01 | 330 | .80 | 570 |
| 25 | 1.87 | 1,650 | —.06 | 290 | .76 | 540 |
| May 1 | 1.84 | 1,650 | —.15 | 290 | .70 | 500 |
| 5 | 1.73 | 1,560 | —.17 | 270 | .68 | 480 |
| 10 | 1.73 | 1,560 | —.21 | 270 | .66 | 470 |
| 15 | 1.71 | 1,560 | —.26 | 240 | .61 | 460 |
| 20 | 1.64 | 1,470 | —.30 | 240 | .61 | 430 |
| 25 | 1.60 | 1,470 | —.35 | 200 | .56 | 400 |
| 31 | 1.55 | 1,380 | —.42 | 180 | .50 | 380 |
| Month. | | | | | | |
| June | —.57 | 175 | .28 | 480 | .47 | 400 |
| July | .51 | 640 | 1.16 | 1,120 | 1.23 | 1,090 |
| August | 4.82 | 5,150 | 3.94 | 3,930 | 4.80 | 4,930 |
| September | 6.83 | 8,250 | 4.76 | 4,780 | 6.32 | 7,040 |
| October | 8.07 | 11,350 | 4.33 | 4,290 | 6.35 | 6,940 |
| November | 6.29 | 7,020 | 3.20 | 3,050 | 4.30 | 4,300 |
| December | 4.08 | 4,030 | 2.18 | 1,960 | 2.86 | 2,700 |
| January | 3.05 | 2,890 | 1.56 | 1,400 | 2.14 | 1,950 |
| February | 2.48 | 2,270 | .89 | 880 | 1.64 | 1,350 |
| March | 2.18 | 1,950 | .46 | 520 | 1.30 | 940 |
| April | 1.94 | 1,740 | .07 | 340 | .87 | 620 |
| May | 1.69 | 1,520 | —.30 | 240 | .62 | 440 |
| Mean of the year | 3.45 | 3,920 | 1.88 | 1,910 | 2.74 | 2,730 |

## V.—Tables and Statistics.

Miscellaneous tables of times and heights of high flood and low water level, disposal of the water of the Nile between Assuân and Cairo, proportion of rainfall discharged into the sea, and approximate quantity of solids discharged into the sea and deposited on the soil of Egypt in an average year at the present time:

*Table giving dates and heights of the real minimum at Assuân.*

[Zero of the gauge means "mean low-water level."]

| Date | *Meters.* | Date | *Meters* |
|---|---|---|---|
| 1873, June 5 | —0.37 | 1883, June 22 | +0.04 |
| 1874, May 30 | —0.64 | 1884, May 27 | +0.37 |
| 1875, May 23 | —0.17 | 1885, June 2 | —0.44 |
| 1876, June 15 | +0.13 | 1886, June 3 | —0.06 |
| 1877, May 27 | +0.10 | 1887, May 8 | —0.03 |
| 1878, June 23 | —0.71[a] | 1888, June 8 | —0.08 |
| 1879, May 23 | +1.88[b] | 1889, June 24 | —0.60 |
| 1880, June 9 | +0.82 | 1890, June 8 | —0.60 |
| 1881, May 14 | +0.00 | 1891, May 19 | —0.21 |
| 1882, June 23 | —0.55 | 1892, June 18 | —0.64 |

[a] Worst low supply. [b] Best low supply.

The river was below the mean low-water level thirteen years, and above seven years. The mean of the minimum is —0.08 meters. In order to find the date of real minimum at Cairo add twelve days to the above dates. The Cairo gauge at this stage of the river is valueless as the regulation at the Barrages affects it.

Very high floods scour out the deepest parts of the river's bed, and a gauge of —0.60 meters in 1878 and 1889, after the poor floods of 1877

and 1888, gave a discharge 25 per cent less than a gauge of —0.60 meters in 1892 after the good and late flood of 1891.

*Table giving dates and heights of the maximum flood levels at Assuân.*

[Zero on the gauge means "mean low-water level."]

| | Meters. | | Meters. |
|---|---|---|---|
| 1873, Sept. 1 | 7.66 | 1883, Sept. 17 | 8.18 |
| 1874, Sept. 6 | 8.97 | 1884, Sept. 1 | 7.73 |
| 1875, Sep. 11 | 8.36 | 1885, Aug. 28 | 8.05[d] |
| 1876, Sept. 7 | 8.68 | 1886, Sept. 22 | 8.04 |
| 1877, Aug. 20 | 6.40[a] | 1887, Sept. 1 | 8.81 |
| 1878, Oct. 1 | 9.15[b] | 1888, Aug. 24 | 7.08 |
| 1879, Sept. 13 | 8.59 | 1889, Sept. 2 | 8.36 |
| 1880, Sept. 4 | 7.82 | 1890, Sept. 2 | 8.72 |
| 1881, Sept. 4 | 8.14 | 1891, Sept. 4 | 7.84[e] |
| 1882, Aug. 28 | 8.00[c] | 1892, Sept. 20 | 8.68 |

[a] The poorest flood. [b] The highest flood. [c] Sept. 22, 7.60. [d] Sept. 10, 8.00. [e] Sept. 27, 7.84.

The late and very high flood of 1892 is being followed by a summer supply in the Nile nearly as high as that of 1879 after the very high and late flood of 1878.

A mean high flood is 7.90 meters; the mean of the maximum is 8.17 meters.

*Table giving the dates and heights of the maximum flood levels at Cairo.*

[Zero on the gauge means "mean low-water level."]

| | Meters. | | Meters. |
|---|---|---|---|
| 1873, Sept. 14 | 5.86 | 1883, Oct. 11 | 7.38 |
| 1874, Oct. 6 | 8.70[a] | 1884, Oct. 25 | 6.52 |
| 1875, Oct. 18 | 7.44 | 1885, Oct. 18 | 6.67 |
| 1876, Sept. 27 | 7.69 | 1886, Oct. 4 | 6.42 |
| 1877, Aug. 27 | 4.95 | 1887, Sep. 25 | 7.93 |
| 1878, Oct. 11 | 8.56[b] | 1888, Sept. 15 | 5.34 |
| 1879, Oct. 1 | 7.60 | 1889, Oct. 16 | 6.74 |
| 1880, Oct. 26 | 6.08 | 1890, Oct. 25 | 7.12 |
| 1881, Oct 13 | 7.38 | 1891, Oct. 25 | 6.72 |
| 1882, Oct. 28 | 6.02 | 1892, Oct. 7 | 7.93 |

[a] Should be 8.25. [b] Should be 8.15.

In 1874 and 1878 the gauges were incorrectly recorded at Cairo. Corrections have been applied by calculations from the Barrage gauges.

The most serious flood of the century was that of 1878, but what its height might have been at Cairo will never be known as the Nile banks were swept away on October 11, while the Nile was rising.

The mean of the maximum is 6.95; a mean high flood is 6.70.

*Table giving approximate dates on which maximum and real minimum guages were reached at Assuân.*

| Number of times minimum. | | Number of times maximum. | |
|---|---|---|---|
| May 10 | 1 | Aug. 20 | 1 |
| 15 | 1 | 25 | 2 |
| 20 | 1 | Sept. 1 | 6 |
| 25 | 4 | 5 | 4 |
| June 1 | 1 | 10 | 1 |
| 5 | 2 | 15 | 2 |
| 10 | 8 | 20 | 2 |
| 15 | 1 | 25 | 1 |
| 20 | 2 | Oct. 1 | 1 |
| 25 | 4 | | |
| | 20 | | 20 |

*Table giving approximate dates on which maximum and real minimum gauges were reached at Cairo.*

| Number of times minimum. | | Number of times maximum. | |
|---|---|---|---|
| May 20 | 1 | Aug. 25 | 1 |
| 25 | 1 | Sept. 15 | 2 |
| June 1 | 1 | 25 | 2 |
| 5 | 5 | Oct. 1 | 1 |
| 10 | 8 | 5 | 3 |
| 15 | 2 | 10 | 2 |
| 20 | 3 | 15 | 3 |
| 25 | 1 | 20 | 1 |
| July 1 | 1 | 25 | 5 |
| 5 | 2 | | |
| | 20 | | 20 |

The date on which the real minimum is reached is the last day of low supply before the final rise begins; occasionally the actual minimum, a few centimeters below the real minimum, precedes the latter by many days.

*Calculation explaining the consumption of water in an average year between Assuân and Cairo.*

[An Egyptian acre equals 4,200 square meters.]

| | Cubic meters. |
|---|---|
| Evaporation off the basins— | |
| 1,500,000 acres × 4,200 × .008 daily × 45 days equals | 2,268,000,000 |
| Evaporation off the Nile itself— | |
| 950,000 meters × 700 meters × 2.00 meters equals | 1,330,000,000 |
| Irrigation of 660,000 acres of land perennially irrigated— | |
| 660,000 × 4,200 × 2.00 meters equals | 5,544,000,000 |
| Escapes directly into the Rosetta branch | 500,000,000 |
| Total expenditure | 9,642,000,000 |

| | Cm. per sec. |
|---|---|
| Mean discharge per day at Assuân, from Appendix III | 3,150 |
| Mean discharge per day at Cairo, from Appendix IV | 2,730 |
| Balance spent | 420 |

Total quantity of water expended between Assuân and Cairo in one year equals 365 × 420 × 86,400, amounting to ........ 13,245,000,000

Therefore the quantity of water absorbed into the soil per annum equals 13,245,000,000 — 9,642,000,000 = 3,603,000,000 cubic meters, and as this is absorbed over an area of 2,210,000 acres, the depth of water absorbed

$$\text{equals } \frac{3,603,000,000}{2,210,000 \times 4,200} = \frac{3,603}{9,282} = .40 \text{ meters.}$$

*Table showing the amount of water which reaches the sea in an average year.*

From Appendix IV, the mean discharge at Cairo = 2,730 cubic meters per second. From this deduct the water withdrawn from the Nile by the Delta canals north of Cairo, viz.:

| | Cm. per sec. | | Cm. per sec. |
|---|---|---|---|
| January | 300 | August | 1,000 |
| February | 300 | September | 1,200 |
| March | 300 | October | 1,200 |
| April | 300 | November | 500 |
| May | 350 | December | 300 |
| June | 400 | | |
| July | 500 | Mean for the year | 554 |

Therefore the discharge into the sea $= 2{,}780 - 554 = 2{,}176$ cubic meters per second, or 68,600,000,000 cubic meters per annum.

As the average rainfall in the Nile Basin has been found to be 2,683,000,000,000 cubic meters per annum, the water which reaches the sea $= \frac{1}{39}$ or say $\frac{1}{40}$ of the rainfall.

*Table giving the quantity of solid matter carried to the sea by the Nile in an average year.*

[See proceedings of the Institute of Civil Engineers, Vol. LX, 1879-'80.]

| Month. | Discharge of the Nile at Cairo in cubic meters per second. | Discharge of the Delta canals. | Discharge entering the sea. |
|---|---|---|---|
| June | 400 | 400 | 0 |
| July | 1,090 | 500 | 590 |
| August | 4,930 | 1,000 | 3,930 |
| September | 7,040 | 1,200 | 5,840 |
| October | 6,940 | 1,200 | 5,740 |
| November | 4,300 | 500 | 3,800 |
| December | 2,700 | 300 | 2,400 |
| January | 1,950 | 300 | 1,650 |
| February | 1,350 | 300 | 1,050 |
| March | 940 | 300 | 640 |
| April | 620 | 300 | 320 |
| May | 440 | 350 | 90 |

*Solids carried in suspension in cubic meters per second.*

| | | | | | |
|---|---|---|---|---|---|
| June | 0 × | 6.9 ÷ | 100,000 = | 0.0 |
| July | 590 × | 17.8 ÷ | 100,000 = | .105 |
| August | 3,930 × | 149.2 ÷ | 100,000 = | 5.864 |
| September | 5,840 × | 54.3 ÷ | 100,000 = | 3.171 |
| October | 5,740 × | 37.8 ÷ | 100,000 = | 2.170 |
| November | 3,800 × | 34.4 ÷ | 100,000 = | 1.307 |
| December | 2,400 × | 28.9 ÷ | 100,000 = | .694 |
| January | 1,650 × | 16.7 ÷ | 100,000 = | .276 |
| February | 1,050 × | 12.6 ÷ | 100,000 = | .132 |
| March | 640 × | 5.3 ÷ | 100,000 = | .034 |
| April | 320 × | 6.6 ÷ | 100,000 = | .021 |
| May | 90 × | 4.8 ÷ | 100,000 = | .004 |
| Mean | | | | 1.1465 |

Total quantity of solids carried to the sea in an average year equals

$365 \times 1.1465 \times 86{,}400 = 36{,}156{,}000$ cubic meters or tons.

*Table giving the approximate quantity of solid matter carried by the Nile at Assuân in an average year.*

[From Table III. Solids carried in suspension in cubic meters per second.]

| | | | | |
|---|---|---|---|---|
| June | 660 × | 6.9 ÷ | 100,000 = | .045 |
| July | 2,080 × | 17.8 ÷ | 100,000 = | .370 |
| August | 7,850 × | 149.2 ÷ | 100,000 = | 11.712 |
| September | 9,810 × | 54.3 ÷ | 100,000 = | 5.327 |
| October | 6,400 × | 43 ÷ | 100,000 = | 2.752 |
| November | 3,550 × | 40 ÷ | 100,000 = | 1.420 |
| December | 2,380 × | 28.9 ÷ | 100,000 = | .690 |
| January | 1,750 × | 16.7 ÷ | 100,000 = | .292 |
| February | 1,280 × | 12.6 ÷ | 100,000 = | .161 |
| March | 920 × | 5.3 ÷ | 100,000 = | .049 |
| April | 630 × | 6.6 ÷ | 100,000 = | .042 |
| May | 500 × | 4.8 ÷ | 100,000 = | .024 |
| Mean | | | | 1.907 |

Total quantity of solids carried past Assuân in an average year equals

$$865 \times 1.907 \times 86,400 = 60,150,000 \text{ cubic meters.}$$

Quantity of solids deposited on the soil of Egypt equals

$$60,150,000 - 36,156,000 = 23,994,000, \text{ or } 24,000,000 \text{ cubic meters per annum.}$$

As the area over which this is deposited is 4,950,000 acres, the depth deposited per 100 years equals

$$\frac{24,000,000}{4,950,000 \times 4,200} = .115 \text{ meters.}$$

Before basin irrigation was changed into perinnial irrigation over two-thirds the area of Egypt the mean deposit must have been considerably greater.

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## 8.—THE BEST MEANS OF FINDING RULES FOR PREDICTING FLOODS IN WATER COURSES.

M. Babinet.

It does not appear to me possible to exhaust in a few pages the subject proposed to M. Lemoine, *Inginieur en Chef des Ponts et Chaussées* at Paris, in charge of the Central Hydrometric Service in the Basin of the Seine, by the Honorable President of Section II of the International Congress of Meteorology, held at Chicago in the month of August, 1893.

Very happily, the task to be fulfilled is well defined by a very clear programme, to which we reply with our best effort, but of which the last two questions apparently ought to be interchanged for clearness of exposition.

### QUESTION I.

*What ought we to propose to ourselves in the matter of flood predictions; ought prediction to be general or specific as regards the stations and the levels which we are to expect there?*

It is not very difficult to predict that a flood river is going to rise when one has knowledge of abundant rains fallen over its basin; the consequences are particularly grave in the higher portions of the country when the impermeability of the soil is there very marked; the slopes of the land there facilitate in every instance the superficial draining or deter evaporation or absorption by the soil. So, then, one may rely on a few rain gauges judiciously distributed and connected with a central station as sufficiently adequate to organize a system of flood predictions.

*Date of maximum.*—This first result which, moreover, must not be considered as altogether negligible, may be improved if we strive to forewarn the inhabitants of a determined locality, in place of simply predicting a rising of the level of the water in a whole region. We shall soon be led to state precisely the epoch when the level will

attain its greatest height at the place considered, from similar phenomena observed up the stream and signaled by the telegraph.

The importance of the principle of the time of propagation of the maximum is thus made evident.

*Importance of the flood.*—We can not admit that a flood has been thoroughly announced if we content ourselves with indicating merely the time of its passage at such and such a point without troubling ourselves with the level it is to attain. Even when the insufficiency of previous investigation and verification does not allow of detailed predictions, if the service is content with simple warnings, there can generally be added to the word flood a qualifying word, such as feeble, mean, or strong. This is a first approximation ordinarily realizable everywhere from the recollections of the people of the country, or from the mean of a small number of observations.

*Numerical predictions.*—To go further and hazard the indication of a stage of determined height on an invariable river gauge, it is certainly preferable to be able to make numerous comparisons between a large number of occurrences of high water. However, the illustrious Belgrand, founder of the Hydrometric Service in the Basin of the Seine in 1854, whose researches are appreciated to-day in the entire world, did not take more than two years to establish a formula for predicting three days in advance the total rise of the Seine at Paris from those of the upper tributaries, as shown by eight well-chosen stations toward the limit of the most distant impermeable lands drained. In spite of the apparent complication of the basin of the Seine, where the water courses of equivalent importance are numerous with their superficial drainage converging on the outskirts of Paris, the same principles applied with perseverance by M. G. Lemoine, pupil of Belgrand, and by his co-workers, have allowed of predicting for the past twenty years the probable levels of the important floods on the Seine and principal tributaries to within 30 or 40 centimeters, or better.

Similar studies inspired or not by the same principles have succeeded as well elsewhere. They have been instituted in France (1st) on the Loire at Orleans, (2d) the basin of the Meuse almost exactly at the time when Belgrand drew from the first results a new science of hydrology of which the announcement of floods is only an application, (3d) on the Saône, the Garonne, the upper and lower Loire, and more recently in several parts of the basin of the Rhône. They did as much in Italy for the basins of the Arno and the Tiber about 1866, a little later on the Elbe in Bohemia, and finally on the Ohio and Mississippi in the United States since 1884. Without considering the most convenient processes for each basin, according to its configuration and the lands that compose it, we can affirm the possibility of predicting floods almost everywhere outside of the

mountainous regions where they are formed, and where their ravages are less to be dreaded than in the fertile plains menaced by the overflow of water.

QUESTION II.

*What arrangement of hydrometric stations on the principal rivers and on their tributaries is the most advantageous for predicting levels?*

The choice of means to be employed for announcing floods, and particularly numerical predictions of heights on certain gauges, depends essentially on the time available for concentrating the information as to the stages at points along the upper courses and the time required for giving information of their results to points lower down. The number of hours depends materially on the rapidity of propagation of the wave, but the facility of transmission of the warnings principally by telegraph plays also an important rôle and at times preponderates in the question.

*A. Long-time forecasts by means of upper tributaries.*—However perfect may be the communication from one point to another along a water course, it is always advantageous to note the indications as far up the river as possible. In this method we are only limited by the multiplicity of nearly equal influences of which it is then necessary to take account.

Thirty or forty years ago the French telegraph system was yet little developed. Warnings were mostly sent by post. In order to have time to receive data for the problem Belgrand had taken typical stations in the circumference of the Seine basin at a convenient distance from the water-parting, approximately on the arc of a circle of which Paris is almost the center. He remarked, moreover, that in these regions, as everywhere else, the water courses from impermeable land carry off almost all the rain that falls over their drainage areas, consequently, they determine the beginning and maximum of floods. In the basin of the Seine the permeable lands cause the level to be sustained for a period of greater or less length, according to the duration of the rain, after the complete saturation of the soil; their levels rise and fall slowly, and their influence is more often negligible or very secondary.

*B. Short-time forecasts by means of several upper observation stations.*—The observation stations used for the announcement of floods at Paris, so reduced to eight, are yet sufficiently numerous for their influence on the result to vary a little from one flood to another, according as the rise is earlier or later at one point or the other. Thanks to the actual rapidity of the telegraphic transmission, the indications that one receives thus from the most distant observers serve to establish three days in advance at least a first approximation, subject to correction by subsequent warnings from nearer stations.

For these corrections, as well as for announcements destined for certain stations less distant from the water-parting, we can utilize the relations which generally connect the maximum level probable at one given point with the corresponding levels observed by two gauges situated up the stream on the two most important water courses of which the union forms the one which passes by the place considered. In order that a relation between three heights of water thus chosen may be utilized, it is sufficient that the first two stages be known long enough before the realization of the third which results from it. It is thus that the levels observed on the Seine at Paris, and on the Oise at Compiègne, allow of announcing the maximum of the Seine at Mantes the next day. The floods of the Marne at Epernay, and of the Yonne at Sens, among others, are generally predicted in their details by the same process. On many rivers whose basins have not the same configuration as that of the Seine, and where the propagation of floods is much more rapid, it may happen that this arrangement of observations gives by itself good results in practice.

If there are more than three water courses of equal importance, the corresponding heights of water of the affluents may be combined, forming a mean, which may be treated as the actual stage at a second upper station, as in the case cited above. It is in this way the announcements of floods on the Loire are made at Nevers.

*C. Use of a single station at a point above.*—The problem is much simplified if the principal water course receives no important affluent for a distance sufficient for the announcement of floods to precede their occurrence. It is this that happens first for the Loire between the points where it receives successively the Allier below Nevers and the Cher at Tours, second for the Saône up the river to Lyons from the confluence of the Doubs. In this case the maximum to be predicted for the lower gauge is a function of a single variable which represents the level attained on the upper gauge. If we develop this function in series according to the increasing powers of the variable, we can at times neglect the second and higher powers when the series is converging; the result is the same as if we admitted *a priori* the proportionality between the two stages.

To facilitate the announcements, the length of river unprovided with affluents ought to be greater in proportion as the slope is more rapid and gives to the water course in consequence a character more torrential. It is impossible to establish very precise general regulations on this subject, for in France, at least, the speed of propagation of the maximum varies much from one river to another and on the same river in different parts of its course; it does not exceed 4 kilometers an hour on the Saône or on the Seine below Paris, while it attains 6 kilometers on the Garonne, 8 to 10 kilometers, and sometimes more, on the Rhône or the Durance. We must have at least

twelve hours interval before us after the maximum occurs up the river in order to give warnings to points below; this is even insufficient if the rise is rapid and occurs in a night.

*D. Importance of the determination of the maximum.—Self-recording apparatus.*—Whatever may be the arrangement of the observing stations, according to circumstances, we can not insist too strongly on the necessity of knowing exactly the maximum, its height, and the exact moment it occurs at each gauge in order to make precise comparisons. The natural law, according to which a variable quantity changes slowly in value in the neighborhood of a maximum or a minimum, and more rapidly in every other case during the intervals between them prevents making any very great errors in this matter in tranquil rivers whose regimen is permanent.

The difficulties are much greater on certain torrential affluents where the observations at fixed hours, however close together they may be in times of flood, allow the most interesting heights to be missed and also the moment of their occurrence. In order to guard against this inconvenience, self-registering apparatus of various kinds is beginning to be be employed in France, not only in Paris and its outskirts, but particularly in the basin of the Durance, the principal affluent of the Rhône, where the slope of the water courses and the rapidity of their floods are quite exceptional. This means of investigation can not be passed over in silence to-day, and will probably permit of pursuing investigations, which otherwise would not give any important result.

QUESTION III.

*What are the best methods for finding rules for announcing floods?*

According to the difficulties considered in the above paragraphs, *A*, *B*, *C*, and *D*, two general processes are recommended for forecasting the levels of rivers at stations: (1) by utilizing the risings of the principal water course and its affluents, that is to say, the differences between the minimum, where the rise of water begins (initial stage) and the maximum, where it ceases. (2) By comparing the highest absolute stages that the water reaches successively at different points during the considered flood.

1. *Announcement of floods by rises.*—The first process is alone applicable to the long-time predictions of paragraph *A*; this is what Belgrand employed for announcing the floods on the Seine at Paris in 1856. It eliminates an important source of error by taking count of the inequalities of the initial stage on the gauge for which the predictions are made. To this stage (variable according to the circumstances which have preceded the flood considered) we add a probable rise calculated by the aid of the actual rises at the stations of observation above; it will generally be a function of the first degree if the development of the series which corresponds to the influence of each gauge up the river allows of considering them as converging rapidly enough.

The study of the rises is particularly indispensable if one considers a multiple flood; that is to say, if a continued great elevation of water on the gauge is produced by many distinct oscillations of the water up stream. The case is presented frequently at Paris, and in the outskirts, where the waters supplied to the upper affluents unite from successive falls of rain. The case in point is due to the permeable lands from which the waters arrive late after those of the impermeable lands and sustain their floods. The highest stages attained by the affluents do not then permit of foreseeing directly the maximum down the river as one would hope if there was only a single rise at each station up stream.

We try, often with success, to take for the probable rise at the station a simple mean of observed rises on the upper secondary basins by taking count of the inequality of the surfaces and of the particular degree of impermeability of each one of them by appropriate coefficients, or by the choice of many stations in the same basin, as Belgrand has done by taking at the same time the rises of the Marne at Chaumont and at St. Dozier for announcement at Paris.

If the hypothetical relation between the rises up and down stream does not appear to be sufficiently simple, the proceedings indicated in the outline sketch by Mr. D. Deague (Gauthier Villars, 1892, pp. 65–81), will permit of giving to it a graphic representation; if necessary, one can state the equations of relation by means of unknown coefficients, and determine those coefficients by the method of least squares, so as to satisfy in the best way a certain number of observed cases; but this method, very laborious, has the inconvenience of not well taking account of the natural circumstances by which the floods are distinguished.

Some rapid "trials," without direct solution, led to the same results, as has been demonstrated by Inspector General Allard (*Annales des Ponts et Chaussées*, 1889, 1er sem., *Le Seine*, Tome I, p. 631).

Nothing proves, moreover, that the relation above mentioned should be a continuous function of the variables it represents, and there are even some chances that it may be otherwise when the real rises surpass certain critical points at some stations, such as certain levels of submersion beyond which the wetted perimeter of the bed of the river changes quickly.

One is thus led to form categories of similar floods for a given station and to modify the formula of prevision according to the categories. A trial of this kind has been made quite recently for many gauges in the basin of the Oise, but in such cases there is great danger of multiplying too much the particular cases so that they are not readily recognizable.

By taking as abscissæ a conveniently chosen function of the rises at certain of the upper stations and as ordinates a similar function

of all the others, and writing by the side of the point thus determined the actual corresponding rise observed at the station for which the prediction is to be made, the locus of the points of equal stage may be considered as the projection of a curve of levels of a surface which will give some idea of how the rises in question are related.

2. *Predictions by absolute stages.*—This representation of a law established between many variable quantities is utilized by M. Mazoyer for the announcement of the floods of the Loire at Nevers (*Annales des Ponts et Chaussées*, 1890, 2d sem., Tome xx, pp. 441–511); but in place of rises the highest levels attained at each point are considered. A similar graphical process had been in use since 1882 for studying the relation between the maximum of the Seine at Rouen, that of the Seine at Mantes, and the level of the open sea at Havre, about thirty-six hours after this latter.

If we consider the simple floods in which the elevation of the water observed at a station arises from a single similar movement observed at a distant station up stream without any intermediate affluent, the comparison of rises is no longer essential. The highest levels attained at both places are then generally in direct relation; in taking the first as abscissæ, the second as ordinates, we often find that the extremities of the latter depart but little from a regular curve which is useful in making predictions. The Hydrometric Service of the Basin of the Seine has established many graphics of this kind which it uses to great advantage.

It goes without saying that the above curves may be replaced by tables of single or double entry; this latter process has been in preference employed by M. Jollois for the floods of the upper Loire (*Annales des Ponts et Chaussées*, 1881, 1er sem., Tome I, pp. 273–322).

## CONCLUSION.

The rules just considered for predicting floods are quite simple enough; for finding them or making application of them, it suffices to observe exactly the heights of the water, either by the eye directly or by self-registering apparatus well maintained. It seems certain that we may obtain thus in most cases satisfactory predictions, particularly by carefully studying the conditions supplied by the greatest known floods.

*Predictions by means of discharges.*—A method rather more complicated, of which the principle is due to M. Harlacher, Professor at the Higher Technical School at Prague, gives, it appears, good results on the Elbe in Bohemia. It might be recommended in analogous circumstances, though it can not be made use of very easily in many other cases such as described above. It presupposes essentially that the progression of the floods at a station depends exclusively on the heights observed at several stations up the stream sufficiently distant

from the point to permit of sending warnings in time to be useful without the rains or affluents of the intermediate region playing any important part. It is necessary, moreover, to have determined for each gauge an exact relation between the height of water and the discharge per second, which presupposes long and minute investigations carried on by the same persons in order to make them comparable.

If the stations of observation are so situated that the water passing them reaches the lower station at the same time there can be deduced from the heights observed at the points above the corresponding discharges, and, by a simple addition, the discharge down stream, which determines the height to be there expected. This method ought to give the best results when, at the stations above, the discharge is strictly defined by the height of the water (which pre-supposes inclosed valleys, on which a great variation of level can be observed for a small change of discharge), and that at the same time down stream an appreciable error in discharge does not involve a great uncertainty in the height of water (which will happen only in a flat valley with a large broad bed). These conditions do not always happen to be united. The Central Hydrometric Service of the Basin of the Seine has tried to apply the method of M. Harlacher for predicting one day in advance the probable maximum at Paris from those of the Seine at Melun, and of the Marne at Chalifert (near Meaux), but without success. The curves of relation between the heights of water and the discharges were perhaps not exact enough; those of M. Harlacher are the result of eighteen years' continued research without change of supervision or control.

*Predictions based on observations of rainfall.*—Finally, in the impermeable basins of certain torrential rivers with heavy slopes, the time available for making predictions from heights of water ascertained up stream, even near the watershed, would be quite insufficient; a case is presented in France, notably in the water courses which flow from the Cevennes toward the Rhône and toward the Mediterranean. As the floods are at times exceptionally disastrous in that region, M. G. Lemoine has quite recently proposed to determine precisely the relations between their height and that of the rain falling some days before. The commission for predicting floods, instituted since 1875 under the Minister of Public Works, has had established provisional flood-warning services predicting on this principle. The relations sought for will probably be indicated most precisely by means of self-registering rain gauges. Investigations of this sort seem to be the order of the day; one may get an idea of them by consulting the *Annales des Ponts et Chaussées*, 1888, 1er sem., Tome xv, pp. 464–510; and 1892, 1er sem., Tome III, pp. 166–196. But they are still theoretical rather than practical, and it remains for the future to perfect them.

## SECTION III.

# MARINE METEOROLOGY.

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### 1.—THE FORECASTING OF OCEAN STORMS AND THE BEST METHODS OF MAKING SUCH FORECASTS AVAILABLE TO COMMERCE.

WILLIAM ALLINGHAM.

Every seafarer will very readily admit that the forecasting of such dread meteors as ocean storms is a far easier matter in theory to the few than in practice to the many. Hence, I approach a consideration of this intensely interesting and highly important subject with a feeling of diffidence verging on despair. The interval allotted for reading the paper is necessarily limited, the field for discussion so vast and fertile, that for mortal to command success in his venture is impossible, however much he may strive to deserve it. Nautical men there are, under every sky in the wide world's navies, whether of peace or of war, thoroughly competent to treat the vexed question of ocean storms from a higher plane than I. The arduous duties of our noble but neglected profession, however, too often preclude close application to clerkly work of this nature, and mankind is thereby a decided loser. I have, therefore, accepted the invitation which you have done me the honor to give, as an earnest that, in the words of the illustrious Maury, a seaman is fit for other things than tacking ship or washing down decks; and in the sincere desire to arouse seafarer's of every nation not only to assist in weather work by recording observations at sea and in unfrequented ports, but also by taking a far more active part in conferences at which nautical matters are brought forward for detailed discussion.

The forecasting of ocean storms is of great utility, both to those that go down to the sea in ships and to those who prefer to gaze upon the mighty ocean from dry land. I have, consequently, deemed it necessary to deal with the subject chosen for me from both points of view. A navigator, remote from the land and the electric telegraph, is perforce his own forecaster of ocean storms; and the gravest responsibility attaches to his decision, inasmuch as a misinterpretation of the scanty data at hand may tend to the total loss of his

devoted bark and all her crew. He will rely upon such signs as sky and sea afford to men whose lives are spent in continual conflict with the elements; while, at the same time, not unmindful of instrumental indications and the published deductions from the experience of navigators who, in some instances, will long since have passed away down the dim corridors of time. An overwhelming torrent of literature relating to the law of storms has flooded the market since it was first formulated, and the ebb is not yet. It would, however, be utterly unsafe to assume that increased certainty has been borne onward by the turbulent, frothy stream of words, either as to the law itself or the deductions therefrom embodied in so-called rules for handling a ship that she may altogether avoid, or partially utilize, the winds of a cyclonic storm. Despite the immense amount of labor bestowed upon tracking these meteors by the aid of synchronous charts, I am reluctantly compelled to confess, without reserve, that navigators have not been supplied with much information of really practical value with respect to ocean storms subsequent to the discovery that they are, generally speaking, circular whirls of varying size and energy; moving onward, now fast, now slow, over the waste of waters. The sailor is unable to depend implicitly on the curiously contradictory conclusions of modern professional and amateur weather workers. He not infrequently finds that his own watchfulness and faculty for generalization are much more essential to safety than all the drawing-room storm maneuvers in existence. Forecasting of storms at sea involves a rapid approximation to the values of several variable quantities; and, having regard to the indisputable fact that weather workers on shore, although assisted as far as possible by electric communication with outlying districts, occasionally forecast a storm which fails to put in an appearance, or let one slip in on them unwittingly, there is matter for congratulation that navigators come out of the ordeal by wind and wave so well. To insure an exact result to any given prediction of an ocean storm the anxious but self-reliant mariner must know the bearing of its center, its distance from the ship, the direction whither it is traveling, and its rate of motion onward. Need I say that the modern book compiler, in a hurry, has only helped to make confusion worse confounded as regards our knowledge of these points. I most heartily agree with a statement referring to ocean storms made by a well-known navigator, Capt. S. T. S. Lecky, R. N. R., that "we can not but feel that to a great extent their origin, shape, and movements are, as yet, purely matters of speculation. So much that is contradictory is daily appearing, and such various plausible theories are being propounded, that it is most difficult to arrive at any safe and practical conclusion."

Probably no great discovery has ever flashed upon the world unless,

and until, a path had been cleared through a dense growth of rank weeds of empiricism, and doubtless many a one came within almost measurable distance of the law of storms prior to the advent of Redfield. The first hurricane on record is perhaps that which Christopher Columbus and his hardy toilers on an unknown, awe-inspiring sea endured for three days and nights of leaden-footed hours in their tiny craft near the Azores in February, 1493. It is, therefore, peculiarly appropriate for prominent mention in this paper when all the world and his wife have set their faces toward the Columbian Exposition at Chicago. Even five centuries ago seafarers noticed that the stormwind did not blow unceasingly from one direction only, but from several points of the compass in succession. The *Philosophical Transactions of* 1698 contain a clearly-drawn word picture of West Indian hurricanes by a Capt. Langford, who was evidently intimately acquainted with some of these undesirable visitors. This old-time navigator pointed out that a West Indian hurricane is a whirlwind, in which the gale commences from the northward, gradually changing through west to south and southeast, which point being attained its fury forthwith abates; or, as the modern mariner, even of the most slender experience, would say, cyclone centers travel westward to the northward of the West India Islands. One page of nature's entrancing book lay wide spread before the observant eyes of that merchant shipmaster, yet he failed to decipher its crabbed characters by the imperfect light which then prevailed in the world of science, even though he quaintly relates that storm warnings sent to more western islands from Dominica and St. Vincent, ten days in advance, were generally correct. He used to get under way and run out before the northerly gale in order to obtain the necessary and sufficient searoom to keep clear of the land when the wind should shift to southwest. Three centuries ago, then, seamen were well aware that West Indian hurricanes are whirlwinds of comparatively insignificant diameter but awful energy, and that they might be fallen in with most often from July to September. Little if anything, however, was known as to their direction and rate of travel. The full, change, and quarters of the moon were considered critical periods, especially if the sun were exceptionally red, the stars with halos, the hills unusually free from cloud and mist, the northwest sky black and foul, or the sea smelling more strongly than its want. Franklin, in a letter dated at Philadelphia, July 16, 1747, wrote that "the air is in violent motion in Virginia before it moves in Connecticut, and in Connecticut before it moves at Cape Sable," thus foreshadowing the result arrived at by Redfield, a naval architect of New York, to whom the world is deeply indebted for the very first reliable enunciation of the law of storms. He gathered together ships' log books, laid down the data thus obtained in their respective geographical positions on simple synoptic charts,

and after several years of patient inquiry promulgated his views about 1831.

After the lapse of more than three score years this dauntless worker in the thorny path of unendowed scientific weather research still stands head and shoulders above all comers, save Maury, who has never been equaled as a passage shortener for sailing ships. Neither the masterly deductions of Redfield nor his well-devised methods of discussion have been improved upon, except in unimportant details. He demonstrated that North Atlantic cyclones have their birth place eastward of the West Indies; that their diameters measure 90 miles and upward; that the wind force increases as the center is approached; that the rate of travel is from 10 to 30 miles an hour along a parabolic trajectory having its vertex, or point of recurvature, near the American coast in about N. 30°; that the changes in wind directions experienced by ships as a cyclone passes over vary according to their positions with respect to its center; and suggested that a cyclone whirled round a cylindrical axis which might be vertical or inclined, and, perchance, staggering on its course afflicted with a kind of nutation, thus causing the violent gusts and intervening lulls met with in the vicinity of the center. There is nothing new in the much-vaunted indraft theory of later writers, inasmuch as Redfield explicitly stated that he merely adopted the circular form of diagram for convenience sake. He deemed the circle good enough to show the fallacy of the straight-line theory of his time, but was not able to conceive that a storm whirl was purely circular, and had not any doubt whatever that in different quadrants of the same storm might be experienced any wind from rotatory to rectilinear. I shall later on try to indicate that this is precisely the position to-day. Redfield happily conjectured that storms of south latitude rotated in an exactly opposite direction to those north of the equator. In the old sailing-ship days, when passages were reckoned by months, not by minutes, British army officers had much sea experience, and sailors should be thankful that some of them observed and discussed the phenomena of ocean storms. Lieut. Col. Reid, R. E., confirmed Redfield's views in every particular; Dr. Thom, of the Eighty-sixth Regiment, came to a like conclusion; and Piddington, of Calcutta, put the finishing touches to the law of storms by the publication of his seaman-like work, which is bad to beat even now. Over fifty years ago it was shown that a single storm may split up into two or more, and conversely; that the winds in a cyclone may be somewhat incurved; that ships under the influence of one should choose the coming-up tack; and the storm tracks in the several seas were well indicated. Rules for storm sailing were made public which still obtain, with slight modifications. In 1849 Capt. Andrews, commander of a British royal mail steamship, impressed upon Col. Reid

that a ship would sail away from the center by keeping the wind on the starboard quarter in the northern hemisphere and on the port quarter in the southern hemisphere; provided, she would steer satisfactorily, and not broach to, a fact only known to those conversant with her sailing qualities. In 1872 Capt. Wales, harbor master at Mauritius, appears to have arrived independently at a similar rule, and this maneuver is now given in the text books. It is to Piddington that we owe the term cyclone, as applied to revolving storms, which he derived from κύκλος; not as some assert as affirming a true circle, but merely a closed curve, for in the Greek that word represents among other things the coil of a snake. There is a serious difficulty in the way of understanding exactly what Piddington and his contemporaries meant by "incurving spirals" and "cycloidal" wind systems.

Modern weather workers have introduced so many tantalizing exceptions to the law of storms that a seaman aware of them would be bewildered. A ship at sea, in a cyclone, is not a fixed observatory. Hence, if this fact be ignored, it follows that arithmetical exercises relative to the angle of indraft will prove exasperatingly misleading. For practical purposes the circular theory is not more uncertain than any other. Blanford asserted that a cyclone center may be from 1 to 5 points before the port beam when running with the wind right aft in the Bay of Bengal; F. Chambers concludes that the indraft varies from point to point around the whirl, increasing from zero to 35° as the observer recedes from the storm center; Capt. Toynbee found that the indraft increases as the center is approached and is more marked in front of the storm; Capt. Whall is firmly convinced that with a good offing the wind blows directly for the storm center in the rear; Ferrel proved mathematically that indraft varies not only with the distance from the center, but also with the latitude. Many other examples might easily be given of conflicting estimates for finding the bearing of a storm center; but enough has said to show that the problem is, so far, an indeterminate one in a great measure. Even the term center has not been satisfactorily defined. Granted that on synchronous charts the shape of a cyclonic disturbance is elliptical, with the major axis in the direction of travel, then is the so-called center a physical point or an area at one or other of the foci, or at the intersection of the axes? Occasionally a cyclone extends right across the North Atlantic from America to Europe, and the question arises as to the bearing of the center of such a system at positions along the closed curve. Abercromby does not help me to form any definite conclusion when he says that the center of a cyclone is displaced toward one side of the oval and may move from one side to the other! Yet the center is the first requisite in forecasting a storm. Comment is superfluous from a nautical point of view.

The average tracks of storms have been approximately known for many years, but even a cursory glance at the 1892 North Atlantic Pilot Charts, published by the U. S. Hydrographic Office, shows that complicated and unexpected divergences from the usual routes occur at times. Similar instances are also noticeable in the erratic behavior of storms over other oceans which would upset the best laid plans of experienced storm forecasters. The storm tracks of 1883, determined by the U. S. Signal Service, clearly indicate that the route most affected by Atlantic cyclones runs from a position south of Newfoundland to the north of Scotland. They drift eastward directly along the track of the Gulf Stream. Some, however, which start well, either die out altogether or proceed due north in mid Atlantic. Others form closed curves and defy prediction. In March one apparently broke up into two distinct cyclones, one of which made the Bay of Biscay, and the other Valentia, on the west coast of Ireland. In April one which had reached N. 50°, W 25°, broke off to southeast, east, and northeast, eventually passing over Brest instead of Aberdeen, as a well-regulated cyclone would have done. Another in mid-ocean traveled east, north, southwest, south, and northeast. In November a cyclone moved eastward to the southward of the Azores for three days; and another in December moving southeast in N. 50°, W. 37°, turned east and northeast to N. 50°, W. 32°, thence north, west, south, and southeast to N. 48°, W. 32°, where it apparently joined forces with another, which, three days later had followed it over Halifax, N. S. The rate of travel is also very variable. One of the above-mentioned storms moved over 20° of longitude during each of two consecutive days, but only 10° during the following forty-eight hours. Occasionally a rapidly-moving storm comes to a halt for a few days and then takes up the running again like a giant refreshed. Mr. R. H. Scott, and others, have referred to this fact at various times. Hence, there is little cause for surprise that the public-spirited attempt of the New York Herald to forecast storms bound across the North Atlantic was not so successful as it deserved to be. The average direction and rate of travel for cyclones over a given ocean avail but little when tracks are not infrequently looped and the onward motion anything up to 70 miles an hour.

The electric telegraph has done much to make easier the lot of a storm forecaster on shore, working in a snug room far distant from an approaching disturbance. Redfield, in 1847, seems to have suggested that this means of conveying storm intelligence between one place and another would be useful. The late Admiral Fitzroy may, however, be regarded as the pioneer of storm forecasting based upon actual observations transmitted by wire from remote stations to a central weather office, to be dealt with there and warnings issued to the seaports when necessary. His predictions were not always in

agreement with the results, but it must not be forgotten that they were tentative, and even now certainty is denied. The idea of warning the coasts of Europe by telegram from ships anchored in the ocean to westward has frequently been mooted, and warnings from North America are, and have been in favor. The Anglo-American Telegraph Company sent messages without charge from Heart's Content, Newfoundland, to England, but the place of observation was unsuitable for the purpose and they were discontinued in 1871. James Gordon Bennett obtained better results in a similar way at his own expense, and France has not lost all faith in this method, as she still receives information from Washington of storms encountered by steamships bound westward. The U. S. Hydrographic Office is in possession of many records of the weather experienced by the Atlantic "greyhounds," and an examination of these passages would perchance determine whether, and how often, a *Campania* or a *Paris* might give reliable storm warnings at either end of the journey, provided every effort were made to obtain such information immediately upon arrival at Queenstown, Southampton, and New York. Her Majesty's ship *Brisk* anchored for six weeks at the entrance to the English Channel as a stationary storm-warning vessel, but she proved a failure. It may be that those responsible did not have their hearts in the work; for Capt. Wharton, R. N., Hydrographer to the British Admiralty, has said that anchoring at sea is not such a physical impossibility as some shore folk believe. Morse thought that simple automatic registering buoys might be dotted over the ocean, and Capt. W. Parker Snow has been bold enough to indicate a cordon of ships at intervals of 500 miles anchored between North America and Europe, in electrical communication with each other and with the land.

If storm warning be worth doing at all it is worth doing well, and money should no more be begrudged in promoting the safety of life than it is to the invention of means for the more expeditious destruction thereof. There should be educated observers, nautical men by preference, familiar with weather indications at their several stations, at Martinique, St. Thomas, Habana, Nantucket, Cape Sable, Cape Race, Valentia, Iceland, Bermuda, Madeira, and Flores, all in communication by submarine cable with the United States and Europe. Science is catholic, and each maritime nation might be required to support this international system of storm warning. If this be impossible, then I would suggest that synchronous charts for the whole globe be undertaken, on which would be carefully laid down the requisite information, but free from an undue striving after artistic effect which adds nothing to their utility though much to their cost. They should be international in every way, and, after the weather workers of each nation have drawn isobars, etc., on precisely the same data, a critical comparison should be carried out by a truly repre-

sentative conference; the best sets chosen, not as specimens of geometrical drawing, but as representations of fact, and deductions for storm warnings made therefrom. An accurate acquaintance with the conditions that prevail twenty-four hours, or more, previous to the passage of an awful cyclone over an exposed roadstead or coast line may be of infinitely greater value to navigators and shore forecasters than the most detailed climatological treatise based upon insufficient data. Similarly, points of vantage in other oceans should be coupled up with the central forecasting establishments in the vicinity and provided with competent observers.

A storm warning to be of use to the shipping community, whom it principally concerns, must fulfill several conditions. It must be of such a nature as to be easily understood by navigators in ships of all nations; it must really be a notification that a gale will blow from a specified direction and proceed along a clearly-defined track, and not merely a record of present weather, or a false alarm; and it should be sufficiently reliable and explanatory to assist seafarers in arriving at a proper appreciation of weather to seaward. In fact, off Ushant and Finisterre, for example, a ship might be informed not only as to the storm expected at either place, but also farther north or south, as necessary. The storm signals should be clear enough to do away with any necessity for reference to telegrams on view in the vicinity. It is not sufficient that a navigator be only informed whether the northern or southern portion of a cyclone is expected to pass over the station displaying the signals. The question as to the best form in which warnings should be made is a strictly nautical one, and might be decided by a committee of representative officers of war ships and merchantmen. The international code of signals might be utilized, notwithstanding the disadvantage of flags in a calm, or blown out directly to or from an observer. They are, however, probably preferable to shapes, such as cones or rectangles; and semaphores find many admirers. Light-ships in connection with the shore by submarine cable, signal stations, life-saving stations, and lighthouses should all be pressed into the service of warning for ocean storms both by day and by night.

I have, doubtless, tried your patience considerably, yet the magnitude and importance of forecasting ocean storms would demand for a due appreciation thereof a far more extended scope. If this paper will but awaken navigators of the world's war ships and mercantile marine to the desirability of making their voices heard more frequently with no uncertain sound on points connected with their well being, I shall not have encroached upon your time and attention in vain. I can not do better than close this necessarily imperfect sketch by quoting the words of Capt. D. Wilson Barker, R. N. R., who has devoted himself to marine weather work, especially in the direction

of cloud observations: "Probably no prognostic is so valuable to a sailor as that afforded by clouds, particularly those of the cirrus formation; and while their value as prognostics has been recognized from the most ancient times, it is only rarely cultivated, and yet I have no hesitation in saying that there is no weather warning for an isolated observer that can in any way compare with them." My old master, Capt. Henry Toynbee, whose name is a household word among officers of the British mercantile marine, Ensign Everett Hayden, U. S. Navy, and other observers have also mentioned the same fact for the benefit of navigators. Capt. A. G. Froud, R. N. R., has just sent me an interesting letter of Vice-Consul Ramsden, at Santiago de Cuba, explaining the method of Padre Viñes at Habana, a well-known authority on West Indian hurricanes, and stating that in Cuba cirrus gives the first indication of the position of a hurricane, and that the clouds "enable one to say whether the low barometer is due to a circular storm or not." Nevertheless, it must not be forgotten that cloud observation requires careful training, and schools for teaching the elements of weather work are conspicuous by their absence on this side of the North Atlantic. Many leagues away, I can not but await your reception of my paper with some trepidation, mindful, however, of the fact that the man of science "loveth truth more than his theory," and that the subject is of itself far more important than the manner of explanation.

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## 2.—THE CREATION OF METEOROLOGICAL OBSERVATORIES ON ISLANDS CONNECTED BY CABLE WITH A CONTINENT.

ALBERT, PRINCE OF MONACO.

During the long periods of time spent on the North Atlantic, on board of my schooner, *L'Hirondelle*, devoted to investigations touching oceanography, and after a careful study of the important labors of American oceanographers and meteorologists, I remain convinced of the utility attached to the creation, upon the scattered islands between Europe and America, of posts of observation daily reporting the state of the atmosphere to a central bureau, as soon as they shall be in direct communication by means of telegraphic cables with either of these two continents.

By means of the meteorological observatories now on the continent we are permitted to forecast, in a general manner, the approach of certain tempests. But what results would be obtained if those perturbations were studied upon the very spot where formed, inasmuch as the surface of the waters gives origin to most of the phenomena which break the equilibrium of the atmosphere.

Meteorological observatories on the ocean, allowing us to trace in a

regular manner the mutation of minima and maxima, the variations of the temperature and winds, would afford the means of distinguishing the principal whirlwinds and the secondary depressions, and enable us to trace the zone of influence of each of them.

The following is my scheme comprehending, in its broad lines, the organization of North Atlantic observatories:

The expenditures for the creation and keeping up of these establishments should be supported in common by the governments of Europe and that of the United States. Individual donations, besides, should be accepted.

The points which I consider as most important for the meteorological observatories of the North Atlantic are the Cape Verde Islands, the Azores, and the Bermudas.

The Cape Verde Islands are situated in a region in which, according to the Pilot Chart, many storms originate, thence going to ravage the West Indies and the coasts of the United States. Those islands are, at the same time, situated along the outer border of the circular movement of the North Atlantic waters, of which my researches upon the currents have shown the existence and the course.

The Azores are situated near the center of this circulation, on which account they deserve special attention, forasmuch as an interesting coalescence occurs between that center and the center of the area of high oceanic pressures when the maximum is bearing westwardly to coincide with that of the Bermudas.

The Bermudas are situated near the western border of the circulation of the waters, not far from the Gulf of Mexico, which plays an important part in oceanic meteorology; moreover, they are under the influence of the Gulf Stream.

With these three points at our command an efficient supervision could be exercised over the North Atlantic. So much the more as at the Cape Verde Islands and at the Azores the height of the mountains (2,974 m. and 2,321 m.) would permit complete observations to be made by means of neighboring posts for the observation of the upper regions of the atmosphere. But such supplementary observations would, for the present, be of secondary importance in the prevision of weather, inasmuch as the inquiry thus far made into the materials collected at the observatory of Ben Nevis shows that observation of the inferior layers is the most advantageous to such a prevision.

It will oftentimes happen that the observatories, if placed at St. Vincent for the Cape Verde Islands, and at San Miguel for the Azores, and on the principal island for the Bermudas, will be in a position, by ships putting into port, to add to the local observations, observations made at sea one or two days previously. Thus, we should pos-

sess, at a given time, a small network of observations covering a surface of several degrees.

For a long time I have been meditating upon the programme of which the broad lines are indicated above. But ere entering into its execution I must wait until the center of observations, the most interesting for Europe, the group of Azores, shall be connected with the continent by a cable. Judging from the actual agitation about that undertaking, it is allowed to hope that the laying of the cable is a mere question of time; the moment seems, therefore, opportune to prepare the desired scheme.

I thought it useful to bring before the intellectual assembly which meets this day in America (scientific representatives of the whole world bestowing a new impetus upon the activity of human intellect) this question of oceanic observatories which, by the manifold services they should return, would soon be multiplied on the surface of the globe.

This question was brought by me last year before the Academy of Sciences of Paris, and before the British Association at its session in Edinburgh; on both occasions the meteorologists and oceanographers of Europe agreed completely upon the desirability of establishing the aforesaid observatories. I am convinced that the American *savants*, always practical and stout hearted concerning enterprises of great scope, will likewise join their efforts to mine in hastening the execution of my plans. Is North America not interested in the same degree as Europe in the possession of advanced information of atmospheric perturbations originating upon the ocean, and which exercise so considerable an influence upon the meteorology of both continents? Unquestionably it is a great progress wanting realization for the advance of modern civilization.

Again, what will be, for powerful nations, the pecuniary sacrifices involved in the aforesaid scheme compared to the ruinous preparations for war which seem rather contemplated to thrust back the human race into barbarism.

At least when these edifices shall arise in the midst of the seas, far from the turmoil of politics and war, will it not be a legitimate compensation to wise men, thoughtful of labor, progress, and peace, and justly alarmed in viewing people armed for destruction? Most certainly so, and the good parole of science announcing new discoveries shall attenuate the voice of cannons.

I come with so much the more joy to lay before you my projects, as I am certain to find with you a similar thought, for you are the descendants of the sturdy men who fought of yore for life and knowledge; you are already the men of the future, contemptuous of the vain glory of conquests.

## 3.—THE MARINE NEPHOSCOPE AND ITS USEFULNESS TO THE NAVIGATOR.

Prof. CLEVELAND ABBE.

The object of the marine nephoscope is to enable the navigator to observe the motions of the clouds, either upper or lower, as easily as he observes the winds. He may not only deduce therefrom the location of a storm center at any moment, which knowledge he needs for his own safety, but may also put on record the data by means of which other students can determine the actual heights and motions of the clouds which will be needed in the further advance that meteorology is sure to make.

I would not assert that we have as yet all the data needed by which the navigator can quickly determine the distance and direction of the storm center at any moment; but we have here the long-needed instrument and I will indicate the method of using it, and the further general process of reasoning, in hopes that this may attract the attention of the navigator to the practical value of the marine nephoscope. The instrument and its use are so simple, and the interest that attaches to the subject is so great, that it is important that navigators in both naval and merchant marine should learn its use and record the motions of the clouds as regularly as they do other meteorological items.

In the gradual development of our knowledge of storms we have historically passed through many stages, *e. g.*, (1) the study of the winds; (2) the study of individual, local, or isolated barometric depressions, namely, the simple rising and falling of an individual barometer; (3) the study of the differences or departures of observed barometers from the normal or average readings of the same instruments at the same altitude above sea level; (4) the study of the relative pressures at many stations all reduced to sea level, and of late years also reduced to standard gravity; (5) the study of the departures of the individual readings, reduced to sea level, from the average pressure proper to the small circle of latitude round the whole globe. Incited by the investigations of Guldberg and Mohn, of Ferrel and other leaders, meteorologists have of late years paid special attention to the angle between the wind and the isobar, but isobars can not be drawn or used by the mariner at sea, neither should the isobar be considered to the exclusion of the effects of temperature and moisture in altering the density of the air; therefore, both for practical and theoretical reasons, the navigator must confine his attention to the angle between the direction toward which the wind is moving at the observer's station and the direction in which the storm center lies with reference to his station.

By storm center we shall in this paper mean the central point

about which rotates a system of whirling winds. We must distinguish between this center of winds and the barometric storm center, which latter is defined as the center of the smallest isobaric circle or ellipse. This latter is the storm center of modern dynamic meteorology; the former is the storm center of the mariner and of the older cyclonologists. These centers are often identical, but not necessarily always so. Mechanical principles have of late years required us to study the relations of the winds to isobars and isabnormals, but having done this we must now return to the older problem and for the use of the mariner, must apply our increased knowledge to the study of the simple geometrical problem that he has to do with, namely, the relation between the movement of the wind and the bearing and distance of the storm center.

As the direction of the wind is so minutely observed by navigators who understand how to determine its true direction, notwithstanding the motion of the vessel on which they are sailing, it should be easily possible by the accumulation of weather maps to determine the direction and incurvature of the wind on all sides of the storm centers at sea. Therefore, up to the present time the navigator has relied upon the wind and its changes to indicate to him the location and movement of the storm center that he wishes to avoid.

The progress of our knowledge of the motions of the upper and lower currents of air in the neighborhood of a well-defined hurricane center has made it apparent that we may improve upon the old rule of the earlier cyclonologists who assumed that the wind blew in a circle around a hurricane center and who, therefore, stated that if in the northern hemisphere the navigator stand with his back to the wind he will have the center on his left hand.

This rule was always recognized as rather crude, yet for a long time nothing better was offered for the use of mariners, notwithstanding the fact that the charts of Redfield, Espy, Loomis, Lloyd, and Leverrier all showed that the rule is not a law of nature. The fact that the winds are inclined inward, as compared with the path required with the truly circular theory, was stated very emphatically by Redfield in 1846, and he adds that in his charts of storms the engraver had sometimes drawn the winds in accordance with the old theory, contrary to Redfield's better judgment. He states that the average inclination of the wind to the circular tangent rarely exceeds two points of the compass, and is never so much as was often claimed by Espy; but it seems to me that the fact should not be lost sight of that the land storms studied by Espy and the ocean hurricanes studied by Redfield are two modes of motion in the atmosphere that are often essentially different from each other.

The rules for locating the center of a hurricane and for determining the direction of its motion, hitherto used by navigators, have been

based largely upon the study of the direction of the wind, but this is subject to considerable local irregularities if the mariner is in the neighborhood of any land; moreover, the inclination of the wind to the radius from the storm center varies largely with the latitude and the position with regard to that center. Numerous studies, especially those of Broun, Ley, Hildebrandsson, Ekholm, and Clayton, have shown that the movement of the wind is subject to considerable irregularity and if the navigator can avail himself of the direction of motion of the clouds he may locate the storm center with much greater accuracy. The most extensive series of observations of upper and lower clouds is that published by Broun in the annual volumes of his observations at Makerstoun, Scotland, for 1843–'46, which form a part of the Transactions of the Royal Society of Edinburg. As the result of about 3,000 observations Broun found that the lower cumulus scud is inclined outward to the winds by 14.5°; the next layer above, or cirro-stratus, inclines outward 22.8°; the highest layer of clouds, or true cirri, is inclined outward 29.6°. These observations were for many years overlooked until, in 1871–'72, both Clement Ley and myself, by the study of English and American observations, respectively, independently announced the general rule, almost in the words that Broun had used twenty-five years before, that as we ascend in the atmosphere the angle by which the movement of a given layer differs from the movement of the lowest wind deviates more and more to the right. As a result of the work that has hitherto been done on this subject I think we may for the present adopt the general rule that between the winds that blow spirally inward and the upper clouds that blow spirally outward there is an intermediate layer of the so-called lower clouds whose motion is very nearly along a circular arc and that the mariner may more safely locate his storm center as being in a line perpendicular to the motion of the lower clouds rather than to rely entirely upon the surface winds. If he observe the angle between the movements of the wind and the lower clouds and again between the lower and the upper clouds, he has a further means of determining even the distance of the storm, although the definite rules for so doing need not now be given.

Assuming, therefore, that the storm center bears at right angles to the direction of movement of lower clouds and is on one's right hand when he faces the direction from which these clouds are coming, it remains only to show how to use the nephoscope in order to obtain the direction of cloud movement.

The accompanying diagrams (Plate VI) present both a horizontal projection and a vertical section of Ritchie's Patent Liquid Compass, as used on American naval vessels, as also a similar projection and vertical section of my marine nephoscope. The compass proper may be described as a heavy bowl mounted on gimbals and so adjusted as

to its axis of gyration that its time of vibration is rather long, namely, about one-half second. The lower half of the bowl is ballasted, and its upper half constitutes a closed receptacle full of liquid, bounded by the circular plate of glass. Within the liquid floats the compass card and needles; the compass card shows not only the thirty-two quarter points, but also every degree of azimuth. The observer looking down upon the plate-glass top sees the compass card, which is just below it, and also the lubber line, *FA*, as marked on the brass rim. As the vessel rolls or pitches the compass card preserves its horizontal position fairly well up to a limiting roll of about thirty degrees. In the standard compass of the U. S. Navy the upper edge or flange of the compass bowl, *EE*, is neatly turned to an exact circle concentric with the pivot and about 9½ inches in diameter. This is for the purpose of setting thereon, at any moment, the alidade and sights for observing the sun and stars, or otherwise determining the true azimuth and the magnetic variations and deviations at any time. Ordinarily, this apparatus is not in place on the compass, and, therefore, without disturbing the regular work of the ship, we may set the nephoscope on the compass in place of the astronomical apparatus. The thin circular vertical flange of the nephoscope is shown in section *RR*, and it fits snugly over *EE*. The nephoscope consists essentially of this circular flange *RR*, whose upper horizontal surface is the ring on which appear the graduations for every five degrees, numbered from 0 around to 360 in the direction in which azimuths are ordinarily measured. In order to revolve this ring horizontally, two small handles, *PQ*, are provided. Within the graduated ring the circular area is covered by a single plate of thin mirror glass of excellent quality, silvered on the lower side. But as it is necessary to look through at the compass card below, the silvering has been removed in a broad circular band; there is also a smaller circle of half its size, as shown by the heavy black line; the outer and inner boundaries of these circles are made quite exactly smooth and concentric with the center of the small black spot, *C*, which is immediately over the compass pivot.

When this silvered mirror is in place upon the compass it represents a horizontal plane, and it preserves its horizontality with remarkable persistence, notwithstanding the ordinary rolling and pitching of the vessel. In the absence of any convenient method of exact measurement, I have been able only to estimate that, in the case of the compass used by me on board of the U. S. S. *Pensacola*, the inclination of the mirror plane to the horizon was rarely more than two degrees, and to this extent, therefore, an uncertainty is introduced into all our measurements; but, as the inclination is perpetually oscillating from positive to negative, we have, therefore, only to take the average of a few observations in order to obtain results

that are appreciably free from this source of error. The observer must, however, be careful to keep the compass in such adjustment that the bowl shall not have any constant error in this respect; of course this same adjustment is also necessary in connection with the observation of the the sun or stars.

In so far as the mirror is horizontal, therefore, a line drawn perpendicular to it at its center is an approximate realization of a standard vertical line on shipboard, and our object now is to determine the motion of the clouds with reference to the zenith and horizon of this mirror. When the observer looks into the mirror he sees reflected therein not only the masts, and rigging, and pennants, but the clouds, and even the sun, moon, and stars. The apparatus is a simple, crude, but convenient altitude and azimuth instrument, and with it we can perform all the operations of determining altitudes, latitude, time, longitude, and azimuth with a very surprising degree of accuracy. I have many times had occasion to set up this nephoscope on shore, and, besides observing the clouds, have determined the altitude and azimuth of the sun; the probable error of a single measured altitude of the sun or moon is about one-quarter of a degree, and could be made still smaller by appropriate changes in the construction. In order to measure the apparent altitude and azimuth of clouds by a method sufficiently expeditious, simple, and accurate for use at sea I devised the hollow tube *SS*, and the sliding rod which fits within it with friction, and which carries at its end the small knob, *K*. The tube has a motion in a vertical plane about the hinge, *S*, and when elevated to any altitude is held there by the friction of this joint. The vertical plane through the tube, the knob, the central spot, *C*, and the hinge, *S*, corresponds with the zero of the graduation of the horizontal rim. The numbering of the degrees is from 0 to 360. The knob and the central spot, *C*, have the same diameter so that in whatever position the knob may be placed (by elevating the tube and sliding the rod in or out) the observer can bring his eye to such a position that he will see the knob reflected in the mirror and exactly covering the spot. Let us suppose that the observer has done this and that he also sees reflected, at *C*, a small bit of cloud or a point in a large cloud, then if he continues to hold his eye in such a position that *K* always falls upon *C* the cloud will seem to move away from the center of the mirror. But he may, if he choose, so move his eye that the image of the knob shall continually cover the selected point of cloud, and if he does this, then both cloud and knob will appear to move together away from the center of the mirror. This latter is the method of observation that is always to be recommended, and if one could keep the cloud and knob together until their reflections simultaneously reach the edge of the graduated rim, he could then read on the rim an angle that represents the

azimuthal direction of their motion relative to the zero of that circle. The position of this zero with reference to the lubber line, *FA*, of the vessel is given by taking from the same circle the reading corresponding to the forward end of the line, *F*; the relation of *F* to the magnetic meridian is given by taking from the compass card, as seen through the unsilvered glass, the angle corresponding to the same forward end of the line, *AF*; the relation of the magnetic to the true meridian is known from the tables of deviations and variatious. These four angular readings, when added together, give the true azimuth of the apparent motion of the cloud.

Inasmuch as we do not often care to wait as long as is necessary for the image of the cloud and knob to move from the center to the edge of the mirror, and especially since it continually happens that the cloud disappears or becomes unrecognizable in the midst of an observation, it is necessary to provide for that class of observations which really occurs most frequently, namely, where the cloud is followed only out to the first small circle whose radius in the present apparatus is exactly one inch; I have, therefore, provided a black copper wire or silk thread that stretches entirely across the circular mirror and is attached to a rather heavy wire forming a circle adjacent to the inner edge of the rim. As this circle with its wire must be easily turned in azimuth, there are provided two small handles, *h* and *h*; by taking hold of these the observer easily brings the thread into such a position that both cloud and knob traverse it together as they move across the mirror, and no matter how short their path may be, the azimuth of their motion is easily read at the end of the thread. We thus provide all that is necessary in order to obtain either the true or the magnetic bearing of the movement of the cloud. It is easy to see how one may utilize the same thread to determine the azimuthal trend of the trail of smoke which a steamer leaves in its wake, or the trend of the streamers and pennants seen reflected in the mirror, and, as all these depend upon the combined motion of the wind and vessel, they have been subjects of regular observation by myself on the U. S. S. *Pensacola*. Moreover, when one wishes to observe the trend of the troughs and ridges of waves, or of the foam that flecks the water with white streaks during high winds, he has here an apparatus more convenient and accurate than the estimates of any but the most skilful navigators, as I can testify from considerable personal experience. Not only the motions of the clouds, but general trend, or the vanishing points of special formations in the cirrus clouds, the boundaries of cloud rolls, the location of the zodiacal light, and the dimensions of halos and rainbows, are easily determined.

By determining the apparent angular altitude and the apparent velocity per second of the cloud under observation, when a vessel is

going at different speeds and in different directions, we may compute the actual velocity and height of the cloud. But I will not here enter upon a complete account of the many problems that can be solved with the help of this simple apparatus; they are mostly questions that interest the meteorologist rather than the navigator. The latter needs the nephoscope mostly in order to determine the true direction of motion of the clouds, and for this purpose, if his vessel is a steamer, he first observes the apparent direction of motion as seen in the nephoscope when going ahead at his ordinary speed; he then slows up a little for five minutes and takes another observation and, if he can, slows up for another five minutes and after getting a third observation resumes his full speed and takes a final observation. The difference between the results obtained at high speed and low speed enables him to easily find what the true direction of the cloud motion is or as it would be observed if the vessel were stationary. If the navigator is on a sailing vessel it is easier for him to observe on two different tacks and the comparisons of the results thus obtained will give him the true motion of the clouds. When the wind has a strength above force 6 on the Beaufort scale, the movements of the lower clouds are apt to be so much more rapid than those of any sailing vessel that the cloud movement is given with sufficient approximation by single observations without the necessity of combining those made on different tacks. Convenient numerical tables will be published in a "Manual of the Nephoscope."

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## 4.—THE BAROMETER AT SEA.

T. S. O'Leary.

Ever since Torricelli, that brilliant pupil of Gallileo, made his famous experiments in 1643, the barometer has been both a familiar and valuable instrument to all civilized nations. It is now absolutely necessary in conducting all scientific experiments where the pressure of the atmosphere is a factor. But so much has been written on its construction, care, uses, and reliability, it would be a waste of time to attempt to cover ground that has already been so carefully gone over. As the subject is a large one it is much beyond the scope of this paper to treat it, though briefly, in all its phases in the time allowed. I shall confine myself, therefore, to a few general remarks.

Although the U. S. Hydrographic Office has been collecting ocean data ever since the time of Maury, it has been within the past few years that special efforts have been made to systematize the collection of these data and use of the same. A great step forward was made when the meteorological log journal, which required observations to be made at twelve different times during every twenty-four hours,

was superseded by the meteorological log book, which requires but one regular observation to be made daily. The hour fixed is noon, Greenwich mean time, so that no matter in what part of the ocean the observations are being made the observers are acting simultaneously. This simplified log was found to be much more desirable than the journal, as observers were induced to continue the work, who, after filling one journal, were apt to decline keeping another on account of the labor involved. The result has been that the number of observers has increased nearly eight fold, so that the oceans are now dotted with many interested workers.

Another valuable feature is the indenture of the leaves of the new log book, which enables the observers to remove the pages as fast as they are filled up and forward them to the Hydrographic Office, there to be utilized in current work. The master of a vessel, or the observer, wants to see the results of his observations while the facts are still fresh in his memory and while he is yet interested in what has recently taken place. The Pilot Chart of the North Atlantic attempts to satisfy this want by placing before the mariner in a graphic form such matters as are deemed of interest or importance to him. For his time and trouble the observer wants a ready return if possible. The accumulation of several years' data in the home meteorological offices, there to be compiled at leisure, then to appear in a volume too bulky for reading and too scientific for the ordinary navigator, with too much attention paid to minor details, is a danger which should be carefully guarded against.

The past has shown that the above cause has driven from the field many good observers who were once interested, and kept out of the field many more whose co-operation would have been of the greatest value. The loss of their services is a direct loss to the science of marine meteorology, but, let us hope, it is not too late to again stimulate them to further efforts.

It goes without saying that mercurial barometers are the best and most reliable, but, unfortunately, a good mercurial instrument is an expensive one. For this reason many sea-going vessels are supplied with aneroids only. Some are supplied with both, but generally the mercurial, the reliable one, is placed in the captain's cabin, where he alone has access to it. On other vessels it is often placed too high, where the light is not good, or more with regard to its safety than its accessibility, so that on a dark night, during heavy weather, the observer experiences no little difficulty in getting even an approximate reading. Generally speaking, the placing of many barometers, especially in merchant ships, is in the interest of the vessel and its owners and not in the interest of science. We must accept the situation as we find it, and deduce from the data furnished the best results we can.

First of all, the most important thing in considering a set of barometer readings is to determine the reliability of the instrument and observer. To do this frequent comparisons with a standard barometer are necessary of readings recorded *by the observer himself.*

A simple plan for obtaining these comparisons has been in use by the U. S. hydrographic offices for the past three years, and the results obtained have been most satisfactory. The credit of the plan is due to the force employed in the Meteorological Division of the Hydrographic Office at Washington, which plan was arrived at after the mistakes and difficulties of former methods in use had been clearly demonstrated. I can not do better than give an account of the plan now in use. Although simple in the extreme, it answers all practical purposes.

On the arrival of a vessel in port the meteorological reports are forwarded immediately to the nearest branch hydrographic office. Accompanying the acknowledgement of the receipt of these reports are two or more franked postal barometer cards, on the back of which are brief instructions showing how the columns should be filled. When in ports of the United States or Canada, observers are requested to record the readings of the barometer used for observations at sea at 8 a. m. or 8 p. m., seventy-fifth meridian time, as at those hours the U. S. Weather Bureau observers record their observations. If the vessels are in those ports where branch hydrographic offices are located, readings at other times will answer, as a record is kept of the hourly readings of the standard in each office. When the cards have been properly filled out they are mailed by the observer to the branch hydrographic office, where each reading is compared with that of the standard instrument for the corresponding time. A copy of these comparisons is immediately furnished the observer. The original cards are forwarded to the Hydrographic Office at Washington, where the comparisons are examined and copied, after which they are returned to the branch offices whence they came, there to be filed away, so that any master or observer can readily find out how his barometer has been acting from month to month or from year to year. In making these comparisons it has been found best to take the absolute difference between the reading of an aneroid and the corrected reading of the standard as the total correction to be applied to all the readings of the aneroid for that pressure. With mercurial barometers the reading is first corrected for temperature; the difference, then, between that result and the corrected reading of the standard is the correction to be applied to the reading of the mercurial. It is evident that these total corrections are but the algebraic sum of the instrumental error, correction for altitude, and personal error of the observer. This last error is of no little consequence, for if the observer is not faithful in recording the observations at the proper time,

his work is no more reliable than that of a faithful observer with an inferior instrument.

It might be contended that the corrections obtained from comparisons made in port when the vessel is light would not answer when she was at sea deep laden. Supposing this difference in heights of the barometer to be 15 or 20 feet the difference of correction would be only one or two hundredths, an unnecessary refinement when it is remembered that in the height of the storm, or when the mercury is "pumping" considerably, an approximate reading is all that can be obtained.

Another method of obtaining comparisons, which has proved quite satisfactory, is by making use of the isobars on the U. S. Weather Maps and the readings at the stations along the coast. As the morning readings are taken at 8 o'clock, seventy-fifth meridian time (or 1 p. m., Greenwich mean time), there is only an hour's difference between the shore readings and the readings at sea. Under normal conditions this is not of much consequence, especially when the pressure changes only a few hundredths in as many hours. Use is made, also, of the 2 p. m. readings of the British Daily Weather Report. It will be seen that "checks" obtained from the readings of a vessel's barometer while in the vicinity of Key West, Jupiter, Hatteras, Block Island, or Nantucket on this side, and again near the outer stations, such as Moville, Valentia, Bishop's Rock, or Dungeness on the other, would determine pretty well whether or not the readings for the voyage should be rejected.

These comparisons are often the only ones obtainable, as the many duties of the officers while in port leaves them little or no time for filling out blanks. Hence, the importance of these shore readings when vessels are adjacent to the stations. It might be mentioned in this connection that the readings recorded on the vessels at the time are obtained under the same conditions, most likely, as those recorded for the previous or subsequent part of the voyage, which fact lends value to the comparisons.

This second method of obtaining comparisons is confined at present to vessels approaching or leaving the east coast of the United States or the coasts of Europe. It is to be hoped, however, that in the near future reliable readings from standard instruments for noon, Greenwich time, will be promptly furnished from the Azores, Canaries, Cape Verde, and West Indies, so that corrections for vessels' barometers can be obtained in much the same manner that a navigator determines his chronometer error when in the vicinity of a place, the latitude and longitude of which have been accurately determined. Without a good idea of the approximate correction to be applied to the readings furnished, the investigator will find it quite difficult to harmonize ocean barometric data.

It is to be regretted that the morning observations for the U. S Weather Service are not made an hour earlier, and the 2 p. m. observations of the British Weather Service two hours earlier. If such were the case, the observers, both on land and at sea, would be working in conjunction with each other, and the simultaneous observations would extend over Europe, the United States, and all the oceans. In the northern hemisphere particularly could the meteorological conditions be studied to better advantage, with observations taken at the same time over an area extending from Russia on the east to the east coast of Asia on the west, or over two hundred and fifty degrees of longitude. The importance of the change suggested and the benefit resulting therefrom are worthy of serious consideration.

The records of the Hydrographic Office for the past three years show that on 5,425 voyages or parts of voyages made by 1,600 vessels the readings of the mercurial barometers were deemed reliable in 4,321 cases, while in the remaining 1,104 cases they were discarded or considered doubtful. With the aneroids, out of a total of 8,898 voyages or parts of voyages, in 4,160 cases the readings were considered reliable, and in 4,738 cases unreliable. In other words, 80 per cent of the mercurial readings could be fairly depended upon and only 46 per cent of the aneroids. These represent about 250,000 barometer readings for the North Atlantic, of which about 130,000 were plotted and 120,000 discarded. The large per cent of unreliable readings can be attributed to many causes, some of which are inferior instruments, carelessness in reading, wrong time for observing, and wrong position given for time of observation. Many of these mistakes have been corrected as the observers have grown more familiar with the work. This is evidenced by the decided improvement to be noticed in the consistency of the readings plotted in the successive volumes of the daily synoptic maps of the North Atlantic. It is fair to presume that in a short time 80 or 85 per cent of all the barometric readings received will be plotted instead of 63 per cent, as previously shown.

The large difference in per cent between the reliable mercurial barometers and reliable aneroids will not escape notice, and while the superiority of the former instruments is undoubtedly established I would hesitate long before casting aside the readings of all aneroids simply because they were aneroids. In many instances, especially in those parts of the ocean the least frequented, readings from aneroids are the only ones obtainable. With a fair correction these readings assist to establish the origin of a "low," perhaps, or prolong a storm track beyond the well-defined paths of commerce. Although mercurial readings are to be preferred the prejudice against aneroids should not be too strong. While some are bad all the time, not all are bad all the time. The lowest reading plotted on any of the daily synoptic maps is that of an aneroid, which was considered tolerably

reliable. At 10 a. m., Greenwich mean time, February 1, 1892, the British steamship *Bellini*, in N. 59° 38', W. 7° 02', had a barometer (aneroid) reading of 27.47 inches. Applying the correction, +0.15, for this instrument, the corrected reading would be 27.62 inches. As the reading recorded by the observer of the British Weather Service at Sumburgh Head at 6 p. m. of that day was 28.02 inches, with steep gradients to the westward, and as the storm center passed to the northwest of the Shetland Islands, it is not unlikely that the corrected reading of the *Bellini's* barometer, 180 miles west of Sumburgh, and near the storm center, was not far from a correct pressure. The correction applied in this instance, +0.15, was obtained from comparisons on this, the preceding, and the subsequent voyage.

The next lowest reading plotted is that of the Dutch steamship *Werkendam* in the cyclone of December 22–23, 1892. At 2 a. m., Greenwich mean time, December 23, in N. 49° 41', W. 30° 41', the corrected reading of this instrument (mercurial) was 704 mm., or 27.72 inches.

The highest reading so far plotted is 790 mm., or 31.10 inches, the corrected reading of the German steamship *Fulda's* mercurial barometer, at noon, Greenwich mean time, January 14, 1891, in N. 49° 57', W. 14° 50'. These readings would indicate that at sea the greatest range of the barometric column occurs in the high latitudes during the winter months, the same as on land, and is about 84 mm., or 3.5 inches.

The importance of frequent comparisons can not be overestimated. To illustrate, the mecurial barometer of a well-known trans-Atlantic liner after being quite regular for two years suddenly changed so that a correction of +0.78 of an inch was necessary. The observer being notified of the fact began using an aneroid. The latter instrument was found to be 0.50 of an inch too high. Here, then, were two barometers on the same vessel with a difference of 1.38 inch in their readings. This is, perhaps, an exceptional case, but it shows that each and every barometer should be carefully "checked" before the readings are plotted as final. Out of the 1,600 vessels previously mentioned the author has taken 70 that had good barometer records. The records show that of these barometers 60 were mercurial and 10 aneroid, and that the average variation of the 70 barometers over a period of twenty-five months was only 0.04 of an inch. Only those records were taken where the variation in the correction applied was less than 0.10 of an inch, and where the barometer had been in use more than a year. The superiority of the mercurial barometers is here again shown by a ratio of 6 to 1. Of the 60 mercurial barometers it was necessary to apply a plus correction with 50 and a minus correction with the remaining 10, which fact might indicate that even with the good observers the tendency is in reading mercurial barometers to move the vernier too far down and thus read too low.

An intelligent interpretation of the prevailing conditions as indicated by the barometer, direction and force of wind, state of sea, and atmosphere, with a view to not only the present, but the future action of his vessel, should be the object of every mariner. At the approach of a cyclone, or even when the storm is on, the action of the barometer together with the shifts of wind will determine the all important point of which tack to lay the vessel on. This done, and the storm passed, the next thing is to take advantage of the future shifts by so laying the course, when first able to proceed, that the different shifts will be provided for beforehand and the vessel allowed to continue on her way without the probability of being headed off. Good judgment in this direction, based upon the knowledge we already have of the general laws of atmospheric movements, will often serve to shorten the passage and bring the vessel into port without much working. It is not only in bad weather, but in good weather also that the master should be on the alert. The approach of a "high," with successive shifts of wind due to that circulation, should be as well understood and maneuvered for as the approach and shifts of a "low," and for the same reasons as given above. This important subject is worthy of the fullest investigation and should be thoroughly mastered by every navigator.

In conclusion, I would beg to submit for your consideration the following suggestions:

That the members of this Congress impress upon their respective governments the desirability and importance of a least one set of simultaneous observations taken daily; that the hour be noon, Greenwich time, for reasons previously mentioned; that all barometer readings be "checked" by frequent comparisons before being used; that a uniform and simple system of recording observations by mariners be adopted; that the recording of observations be encouraged among shipmasters and officers, and also the study of ocean meteorology by putting before them from time to time, and in as graphic a manner as possible, the explanation of the general laws of atmospheric movements and such other matters as would be beneficial to them; and finally, that all the data collected be used in an exhaustive manner to the end that from a thorough investigation of the results obtained our knowledge of the subject of ocean meteorology may be considerably increased.

## 5.—THE SECULAR CHANGE IN THE DIRECTION OF THE MAGNETIC NEEDLE; ITS CAUSE AND PERIOD.

G. W. Littlehales.

A freely suspended magnetic needle is observed to be in a state of continuous tremulous motion of an involved character which may be resolved into irregular and periodic. The irregular motions comprise those sudden and rapid fluctuations in the direction of the needle which can not be predicted. The periodic motions are the solar variations which include the solar-diurnal variation depending upon the hour of the day, the annual variation depending upon the day of the year, and the solar-synodic variation depending upon the synodic revolution of the sun, the lunar variations depending upon the moon's hour-angle and her other elements of position, and partaking of the character of the tides, and the decennial variations which may depend upon the frequency and magnitude of the solar spots. Both the irregular and periodic motions referred to are of such small amplitude in all except the polar regions of the earth that they do not effect any of the practical uses of the magnetic needle on the sea, but besides these there is another motion, having an amplitude reaching thirty or forty degrees in some parts of the world, which is also supposed to be of periodic character, and which, although not perhaps so intimately connected with the meteorologic problems of the day as the variations of smaller amplitude and period, is doubtless of radical importance in meteorologic science.

At a particular instant of time the lines of magnetic force at any place, to which a freely suspended magnetic needle will set itself tangent, will have a certain direction and strength. The angle between the plane of the astronomical meridian and the vertical plane passing through the needle, or the line of force, is the magnetic declination, or the variation of the compass; the angle between the horizon and the direction of the needle, measured in the vertical plane passing through it, is the dip, or inclination; and the force with which the needle is held in the direction of the lines of force is called the magnetic intensity. The declination and inclination, or the directional elements, which alone are concerned in a discussion of the motion of the magnetic needle, have always been treated separately in investigating the secular change of the magnetic needle. From 1634, when the fact of the secular variation of the declination was established, and from 1676, when the inclination or dip was discovered, reliable observations of these respective elements are recorded for the great populous centers of Europe, and soon observations of the declination or variation of the compass, a knowledge of which is necessary to mariners in the navigation of their ships, had been made by navi-

gators in most of the known parts of the world. Although the older observations, having been made without the means of precise measurement, are subject to a probable error of as much as 1°, they can be accepted as serviceable in the discussion of long series and serve to reveal satisfactorily the secular change of the declination. Through the results of the observations of the navigators of successive periods, series of observations of the declination extending over two or three centuries are available for most of the important maritime stations of the world. On plotting the observations at a given station with reference to rectangular co-ordinates, using values of the declination as ordinates and intervals of time as abscissæ, sinuous curves are developed which suggest the periodic character of the secular variation, and it is now customary to adapt to the series of observations for their discussion a periodic function of the form

$$V = A + B_1 \sin. \frac{360}{m} t + B_2 \cos. \frac{360}{m} t,$$

in which $V$ represents the variation, $m$ the period of the cycle, $t$ the time in years and fractions of a year reckoned from some assumed epoch, and $A$, $B_1$, and $B_2$ constants to be determined from the observations.

In this manner the rate of movement of the compass needle is found for any epoch within the range of observation, the times when the needle is stationary are computed, and values of the declination are predicted for current use for ten or fifteen years beyond the limits of observation within an assigned measure of precision. An examination of the curves resulting from plotting the observed and computed values of the declination at a few stations, where the series extend over the greatest duration and are the most complete, will show upon what evidence rests the widespread belief that the secular variation of the magnetic declination is a periodic phenomenon.

There are also available for discussion series of observations of the dip or magnetic inclination ranging from one hundred to three hundred years in duration, but the stations are not so numerous nor the observations so complete as in the case of the declination, except in the long-settled regions of European civilization. This is accounted for by the fact that the dip was rarely observed by navigators, except when employed in expeditions of scientific research, while the declination was found as a necessary performance in the navigation of their ships. The investigation of the longer series has led to the belief that the secular variation of the inclination is also a periodic phenomenon; but the data which have been observed up to the present are manifestly insufficient to warrant a conclusion that after a certain period has elapsed the declination at any given station will be the same as it is now and will then repeat its changes and again assume the same value after the lapse of the same interval of time, or

that the inclination at that place will be found to pass through a cycle of changes and return to the same value at regular intervals of time. While the separate investigation of series of observations of declination and inclination is of great practical usefulness in gaining a knowledge of the rate of secular change of these elements and predicting values beyond the range of the observations, in seeking to discover the causes of the secular change in the direction of the magnetic needle and to establish or disprove its periodic character the declination and inclination should be viewed as component effects of the forces that are acting. Such a view brings us to the investigation of the successive directions in space assumed at successive epochs by a freely suspended magnetic needle or the consideration of the observed values of the declination and inclination conjointly, instead of the separate consideration of values of the direction of the compass needle and of the dipping needle. As a freely suspended magnetic needle assumes its successive directions for different times, it describes a conical surface whose vertex is the center of gravity of the needle.

If a sphere of any convenient radius be described, with its center coinciding with the center of gravity of the needle, and the conical surface be extended through the surface of the sphere, the line of intersection will be a serpentine curve whose geometrical nature should be fully investigated, since it represents the actual secular motion of the needle. Preliminary analytical and graphical attempts have been made by Quetelet, of Brussels, Schaper, of Lubeck, and the mathematicians of the Coast and Geodetic Survey. The scantiness of data has prevented any safe deductions as to the future course of the needle.

At the present time we know, with moderate accuracy, the values of the three magnetic elements for the inhabited portions of the world, and also, with a lesser accuracy, the rates of secular change in the elements, but we have no knowledge as to whether the needle, when it points in a certain direction at a given place, will ever return to the same position again, or whether it will at the end of a certain period assume the same direction again, and again sweep over the same path in the same period. Nor do we know that the secular-variation period, if there shall hereafter be found to be one, will be the same in all parts of the world.

To promote the study of the secular change it is proposed that this Congress shall take steps to secure the co-operation of observers at the following-named places to make yearly observations of the dip and declination at selected stations and to arrange and transmit them to the U. S. Hydrographic Office at Washington where their discussion will be undertaken:

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| Christianshaab | Greenland. |
| Saint Johns | Newfoundland. |
| Acapulco | Mexico. |
| Mazatlan | do. |
| Mexico | do. |
| Vera Cruz | do. |
| San Juan del Sur | Nicaragua. |
| Callao | Peru. |
| Conception | Chile. |
| Valparaiso | do. |
| Belize | British Honduras. |
| Cartagena | U. S. of Colombia. |
| Colon | do. |
| Panama | do. |
| La Guayra | Venezuela. |
| Kingston | Jamaica. |
| Port Castries | West Indies. |
| Saint Thomas | do. |
| Bahia | Brazil |
| Para | do. |
| Pernambuco | do. |
| Rio de Janeiro | do. |
| Montevideo | Uruguay. |
| Buenos Ayres | Argentine Republic. |
| Sandy Point (Punta Arenas) | Patagonia. |
| The Azores | |
| The Canaries | |
| Cape Verde | |
| Bermuda | |
| Cape of Good Hope | Africa. |
| Congo River | do. |
| Delagoa Bay | do. |
| Libreville | do. |
| Loanda | do. |
| Port Natal | do. |
| Quilimane River | do. |
| Zanzibar | do. |
| Port Louis | Mauritius. |
| Hellville | Madagascar. |
| Aden | Arabia. |
| Singapore | Malay Peninsula. |
| Saigon | Siam. |
| Pekin | China. |
| Hakodate | Japan. |
| Nagasaki | do. |
| Vladivostok | Siberia. |
| Petropaulovsk | Kamchatka. |
| Sitka | Alaska. |
| Unalaska | do. |
| Honolulu | Hawaiian Islands. |
| Tahiti | Society Islands. |
| Levuka | Fiji Islands. |
| Apia | Samoan Islands. |
| Melbourne | Australia. |
| Port Darwin | do. |
| Sydney | do. |
| Auckland | New Zealand. |
| Wellington | do. |

## 6.—RELATIONS BETWEEN THE BAROMETRIC PRESSURE AND THE STRENGTH AND DIRECTION OF OCEAN CURRENTS.

Lieut. W. H. BEEHLER, U. S. Navy.

The student of ocean meteorology can hardly fail to notice a striking similarity between the average annual curves of isobars and the general circulation of the main currents in the five great oceans.

The general circulation of the winds around the almost permanent centers of high pressure in the North and South Atlantic, the North and South Pacific, and Indian oceans, deduced from observations of wind directions extending over many years, has been demonstrated by their coincidence with the curves of isobars to be in accordance with the first principles of meteorology.

There is a most intimate relation between the barometric pressure and the wind force and direction. The character of the gradients of barometric pressure is the best evidence of the force of the wind, and the great practical value of the barometer to mariners consists in the feature that the changes in the barometer readings are the most reliable of all the indications of change in the weather.

The North Atlantic Pilot Chart for June, 1893, has three charts of the North Atlantic, the main chart and two small subcharts, one of which is a chart of the curves of isobars and isotherms which observations of many years indicate to be the normal condition for the month of June, and the other is a chart showing the average annual set of the surface currents of the North Atlantic.

Unfortunately there are no monthly charts of the currents, but the comparison of these three charts suffices to invite scientific investigation of this coincidence to determine if there be any law governing the relation and the manner and effect of its operations.

I submit the remarks on the Pilot Chart in relation to this analogy between the movements of the air and the curves of equal barometric pressure:

The strength of the surface currents is indicated by the proportional quantity of the arrows on the chart. The greatest number of arrows are drawn where the currents are strongest. There is doubt about the direction and strength of these currents in certain parts of the North Atlantic, and our voluntary co-operating observers among mariners of all nations are requested to continue their observations to ascertain the exact set and strength of surface currents.

In the Bay of Biscay recent investigations indicate that the Rennell current, as shown on the main chart, setting along the north coast of Spain east to the coast of France, and thence north and north-northwest athwart the current setting up the English and Irish channels, does not exist, at least during the summer months; but, on the contrary, it is claimed that currents set in a south-southeasterly direction into the Bay of Biscay, and thence westward along the north coast of Spain. No doubt there is a large volume of water from the Gulf Stream which enters the Bay of Biscay and must escape and cause surface currents to set out, some around Brest into the English Channel, and some around Cape Finisterre down along the coast of Portugal, the set depending largely upon the direction of the prevailing wind.

By comparing the blue wind arrows on main chart with the small barometer chart and the small current chart, a striking similarity appears between the curves, showing equal barometer pressure, directions of the winds, and the general directions of the ocean currents. Among the causes which operate to produce and influence the winds and currents, this comparison suggests that the varying barometer pressure may be one of the original causes as well as a final influence on the direction of the currents, directly by its varying pressure, as well as indirectly through its relations to the winds. To what extent the barometric pressure is a factor in influencing ocean currents invites careful observations. The strength of the currents depends largely on the contour of the coast, as, in the northwest part of the Caribbean Sea, where the water is raised by the westerly current, and flows through the Strait of Yucatan into the Gulf of Mexico, a reservoir which discharges through the Strait of Florida and gives abnormal strength to that part of the current system of the North Atlantic known as the Gulf Stream.

In the practical presentation of meteorological conditions the Pilot Charts meet the purpose for which they are published, and Lieut. Commander Richardson Clover, ex-Hydrographer, merely intended to invite scientific investigation of this relationship of currents to wind and barometric pressure with the hope that it may lead to ascertain truths of practical application.

The late Prof. Wm. Ferrel published a number of letters and

articles in relation to ocean currents and sea level in *Science* in 1886, and he concluded that the wind has little or no effect in producing ocean currents. These articles excited considerable attention, and were criticised because his theories on the ocean currents were based upon statements in regard to a difference of one meter between the sea level of the Gulf of Mexico and that of the Atlantic Ocean near New York.

It is not possible in the limit of this paper to enter into all the details of the discussion of the causes which produce ocean currents. Prof. Ferrel advocated the difference in specific gravity between cold Arctic and warm tropical water as the chief factor, and that the wind was only a temporary disturbing or a locally contributing agent, while Prof. Newberry admitted the gravitation theory as a cause but a less effective one than the friction of the wind.

In Croll's *Climate and Time* there are chapters discussing the gravitation theory and wind theory in a manner which might be supposed to be conclusive, but the necessity of further investigation is still apparent, because the effect of differences in atmospheric pressure was overlooked.

Naturally mariners have been practically investigating the subject of ocean currents more than scientists who do not go to sea, and while the former may not make such elaborate, painstaking researches and calculations, their actual experience of the ocean surface currents must have weight as well as statements of the existence of currents deduced from theory alone.

The statement that the wind has little or no effect in producing surface currents can not stand in the face of the almost universal experience that currents are generally found setting to leeward during and after a gale, excepting when in a well-known, strongly-defined current like the Gulf Stream, a wind blowing against that current may not entirely counteract it, but will, on the surface, retard its surface velocity and cause a high, rough sea.

Capt. Hoffman, of the German Navy, in a pamphlet (*Zur Mechanik der Meereströmungen an der Oberfläche des Oceans*, Berlin, 1884) brings out the value of the wind as the chief motive force, and shows the inefficiency of gravity due to difference of temperature to produce ocean currents. The part played by deflective forces due to the earth's rotation is also well stated, but as long as waters are brushed along by the wind in any direction the tendency to depart from that direction due to the deflective force of the earth's rotation is overcome, but where there is a belt of calms they begin to describe an "inertia curve," a line whose radius of curvature decreases with the sine of the latitude. In latitude 5° this radius of curvature for a velocity of one meter per second is only 42½ miles, hence, when the South Atlantic Current runs into regions north of the equator, its waters turn to the

right and form the Guinea Current, and, during the northern summer, the Equatorial Counter Current. The author concludes that the winds are first, then configuration of coasts, then the rotation of the earth, and, finally, the force of gravity in their relative influence to produce currents.

The wind blows horizontally parallel with the surface of the sea, or inclined at an angle either upward or downward. In the first case the parallel motion would have some effect by its friction, and much less if the wind be upward, but where inclined downward the downward pressure causes a depression and forms a ridge of water in front of this depression which offers resistance and is carried along with maximum effect. Where waves are formed the crests are impelled along by the wind and a considerable volume of surface water is necessarily transported by the wind. To what extent the wind carries the surface water to leeward depends upon its force and continuance. In cases where a storm wave meets the sudden resistance of coast line the shores have been indundated to a depth of from 20 to 40 feet, as is reported in the account of the six typical Bay of Bengal cyclonic storms in the "Hand Book of the Cyclonic Storms in the Bay of Bengal," published by the Meteorological Department of the Government of India.

These facts appear to me to indicate that the direction of ocean currents is most frequently to leeward. On Berghaus' Physical Atlas No. 21, *Seeströmungen*, the ocean currents in connection with the areas of the permanent high air pressure in the different oceans are indicated. The wind circulations and curves of isobars are here also shown to coincide.

The analogy between the curves of isobars and the directions of winds and currents is therefore evident. It only remains to demonstrate the nature of this relation and, if possible, reconcile all the theories of scientists with the experience of mariners.

The most effective manner in which the wind can act upon the surface waters to produce a current is where it is inclined downward, and where the friction of the moving air is enhanced by its pressure down upon the water.

Those areas of high pressure, more or less permanent in latitude 28° north and south, must necessarily exert by their weight of air *a greater pressure* upon the water upon which they rest than lesser weights of air in areas of lower pressure exert upon the water in other parts of the ocean.

The differences in temperature, differences of level, and rotation of the earth must combine to give a complicated, unstable resultant effect of this atmospheric pressure upon the sea. The first three conditions may be in operation, but the varying operation of the atmos-

pheric pressure must cause the final resulting effect upon the surface water.

The curves of isobars around the "high" on opposite sides of the equator would leave the equatorial regions with less weight of atmosphere than where the areas of high pressure exist.

The "World's Chart of Isobars" shows that there is a normal atmospheric pressure on both sides of the equator from about N. 10° to S. 10°. This pressure is 760 mm., or 29.92 inches.

The area of normal high barometer, 30.16 inches, southwest of the Azores, is about 700,000 square miles, and the weight of that mountain of air is 227,000,000,000 tons *greater* than the weight of air over an equatorial belt of equal area south of N. 10°, where the barometer is normal, or 29.92 inches, one-quarter of an inch lower than the "high."

The researches of the *Challenger* expedition claim to have established that the general surface of the North Atlantic, in order to produce an equilibrium must stand at a higher level than at the equator. I claim that a difference of level must be the difference of effect of atmospheric pressure. The pressures under the areas of high barometer would make those areas of lower level than the equatorial regions, but the section of the Atlantic examined by the *Challenger* on W. 40°, and between N. 38° and S. 38°, puts the higher level near the extremities. By computing the effect of heat, Dr. Croll states that the surface level at N. 38° is 3½ feet higher than at the equator. But the *Challenger* researches did not consider barometric pressure as a cause to lower the sea level. Only a small part of the ocean was examined, and it is probable that further research will demonstrate that the lowest level of the ocean is under the area of the highest barometric pressure.

The isobars at about N. 40° show that the pressure there is the same as on the equatorial belt. The gradients north of 40° are steeper, and the difference of level should be greater. In the North Atlantic the area of low pressure is near Iceland, and the effect of the barometric pressure should make that the highest level.

In the sketch the downward pressure of the atmosphere in the "high" and its upward pressure in the "low" are illustrated. Manifestly the enormous difference of pressure must have the effect upon the incompressible water to push it away from the region of the "high" to that of the "low."

This causes variation in the sea level and surface currents. The true final direction of the currents must be in the direction of the resultant of the force of atmospheric pressure, the wind, and the rotation of the earth. Generally, as the angle which these first two forces make with each other is small, the resultant will be nearly to leeward. Its strength will depend upon these forces, together with the specific gravity of the water, the time the forces were acting, the acquired

momentum, the pre-existing condition of surface whither the currents flow, and the limiting slope of the raised sea level. The gradients of high barometric pressure are constantly varying and unequally distributed, the pressure acts on the water with a downward, outward, spiral motion as on the air, and currents flow with the wind or at an angle with it, depending upon conditions of surface just mentioned.

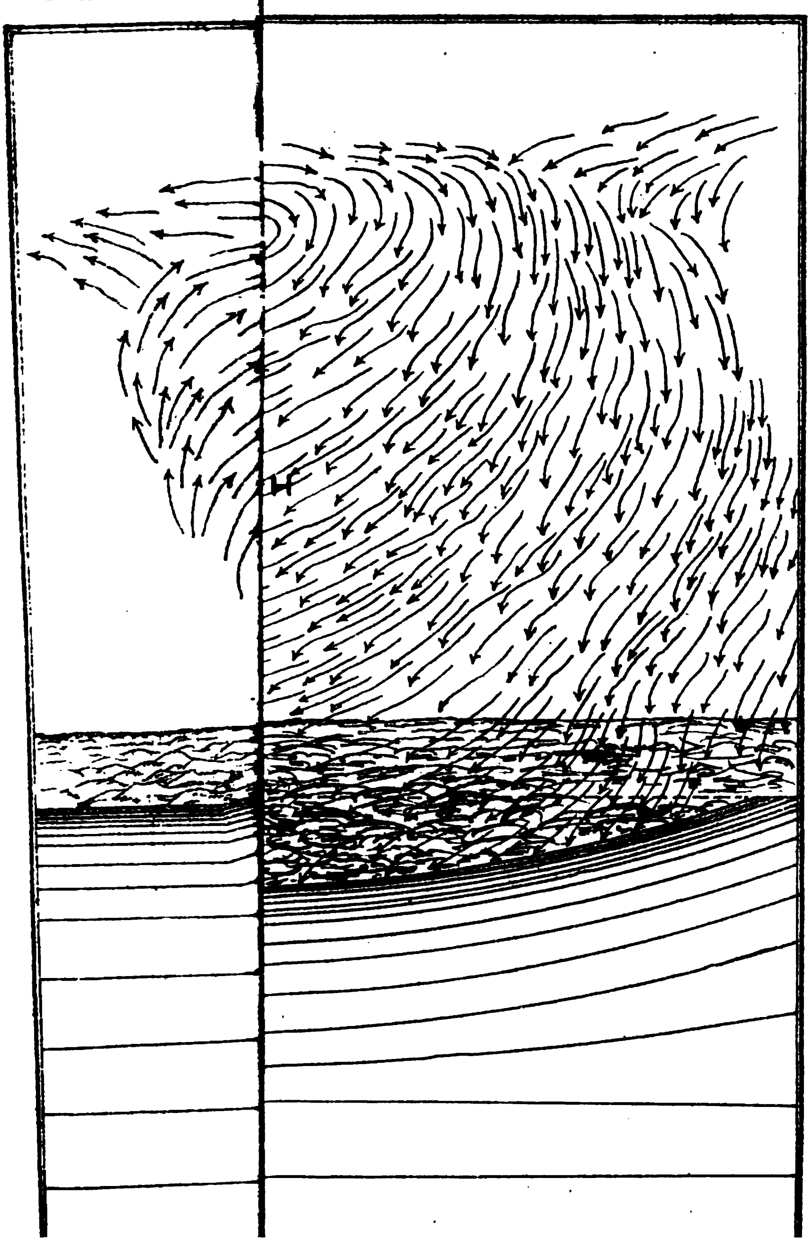
The investigations of the Prince of Monaco in the yacht *L'Hirondelle*, during the summers of 1885 to 1888, on ocean currents show a much closer analogy between the curves of isobars and surface-water circulation, especially in the elliptical movement in and around the Saragossa Sea. The Azores are shown to be on one of the curves, and the drifts of the *L'Hirondelle* floats describe ellipses varying in diameter from 200 miles to the coast lines on both sides of the Atlantic. The drifts of derelicts and thousands of ocean current reports by bottle papers of the U. S. Hydrographic Office indicate the same conformity of surface drift with the curves of isobars.

The configuration of the coast line has an effect upon the circulation, and the explanation quoted from the June Pilot Chart fully explains the abnormal Gulf Stream Current.

The effect of the barometric pressure on the Gulf Stream has been well established, and in Lieut. Pillsbury's report on "Gulf Stream Investigations and Results," there is one chapter devoted to the cause of the Gulf Stream and of Atlantic currents. After a very thorough examination of the gravity and wind theories, he advocates the wind theory as the principal cause, but in the closing pages of the chapter he explains abnormal currents by the effect of barometric pressure. He states that a difference of one inch in the barometric column, or about half a pound in atmospheric pressure, will give over one foot difference in the elevation of the surface of the sea.

The chart of isobars for the year shows that there is a region in the North Atlantic between about N. 10° and N. 40° of about 9,600,000 square miles where the barometric pressure is above the normal, 29.92 inches, 760 mm. North of this zone there is an area of ocean surface of about 2,300,000 square miles where the pressure is below the normal.

The maximum high is about 30.16 inches and the minimum low is 29.69 inches, or a difference of about 0.47 of an inch. If one inch in the height of the barometer represents about half a pound in the atmospheric pressure per square inch, the total difference of the weight of atmosphere upon these regions reaches an enormous figure, sufficient to cause a very decided difference between the levels of the sea at the areas of the maximum high and minimum low. (This difference, I believe, amounts to about 20 meters.) The surface water will be forced up an incline in the region of the "low." The lack of pressure, or rather the diminished air pressure in the low region taken in con-



nection with the lesser area, will still farther enhance the accumulation of the water in the region of the "low."

The atmospheric pressure in the Atlantic causes the accumulation in the western part of the Caribbean Sea, and the sea level there and in the Gulf of Mexico is one meter higher than that off Sandy Hook, N. Y.

The Gulf Stream, thus formed, unites with the waters of the Atlantic circulating around the "high" and flowing up along the Bahamas and following the United States coast line to Hatteras. The waters continue on, but after passing the Grand Banks they meet with no further coast resistance and are pushed out by the barometric pressure, which is constantly diminishing, into the Arctic until the upward slope is so great that the diminishing pressure can no longer force the water there. A large volume of water flows down between the Azores and the coasts of Portugal and Africa, where the pressure is less than the maximum, and then continues circulating around as before.

The water thus continually pressed away by the high pressure from the mid North Atlantic must be replaced, and consequently there are undercurrents of cold water from the Arctic and northern part of the North Atlantic to restore the equilibrium. These cold currents will, on account of their specific gravities, fall below the warmer surface currents, and while this barometric pressure is acting, these cold currents flowing south cannot appear on the surface, for if they did appear they would, under normal conditions, be necessarily brushed back again toward the Arctic.

Where the configuration of the coasts has deflected this circulation of water away from the shores, the cooler currents may there appear on the surface, and, consequently, we find a cold current from the Arctic along the coast of Labrador, sneaking in around Newfoundland and close along the United States coast to Hatteras and Florida.

In the report for 1891, Appendix No. 10, of the U. S. Coast and Geodetic Survey, Prof. E. E. Haskell publishes an account of observations of currents in the Straits of Florida and Gulf of Mexico, and on page 347 he states:

> Over a water surface unequal atmospheric pressure and wind both become causes, acting generally at an angle with each other to produce a current. The former is the equivalent of a head to be spent as a gravity force in the direction of the trend of the barometric gradient, while the latter acts by friction on the surface to produce a current in its direction. There is little or no information extant as to the current that any known velocity of wind and barometric gradient will produce, nor is there a definite enough relation between direction of wind and trend of barometric gradient to permit of making more than the general statement that the current should be in the direction of the resultant of the two forces.

I quote this by permission, and this pamphlet contains tables connecting the observations of currents with meteorologic data. I also

have in a letter from Prof. Haskell the further statement that, "If I had at my command daily observations of the direction and force of the wind and the reading of the barometer from stations so located as to surround the Gulf, I could predict the currents much as our weather is predicted."

In investigating the ocean currents it must be remembered that the mountain of air in the region of the almost permanent "high" is not constant in extent or in exact locality. I have taken the average annual location and direction of the areas of the "high" in the North Atlantic. This varies, and the Pilot Chart for each month shows these variations graphically. Again, near the belt of normal atmospheric pressure the air circulation around the "high" is accompanied by other circulations, both cyclonic and anticyclonic, and these storms will temporarily disturb the normal condition and cause variations in the current both in strength and direction.

To follow the movement of a cyclonic circulation across the Atlantic toward Europe and the Arctic the waters under the center must be relieved of pressure by the extent of the abnormal difference of air pressure. The winds also in the cyclonic circulation flow in, around, and upward, and these causes must contribute, not only to raise the level of the surface water, but also to make this increase of level to take place in a comparatively small circular space; hence, the remarkable high, almost vertical, seas which are raised and fall with such destructive effect all around in a confused mass in the center of a cyclone.

The storm waves quoted from the Bay of Bengal typical cyclones are explained on this theory, and further examples might be quoted to show that the currents of all oceans and at all times are chiefly due to the atmospheric pressure. Our knowledge of the ocean currents is far from exact, and the object of this paper is to invite investigation of the subject of ocean currents in connection with the barometric pressure.

It is extremely difficult to ascertain the direction and strength of ocean currents. As a rule the reports of currents experienced are really the difference between an estimated run of a ship in twenty-four hours by dead reckoning and the more exact run as determined by astronomical observations. All the errors of the estimated course and distance made good for twenty-four hours are added and ascribed to currents which, for half the time, may have been in one direction at one rate and at other times in other directions at different rates.

With the sextant it is rare that a captain can determine his position more than once in twenty-four hours, and until he has means of finding his position accurately at sea more frequently, the reports of currents experienced will be unreliable.

I have recently invented a nautical instrument, the solarometer,

by which a vessel's exact position can be determined at sea at any time of day or night that any heavenly body is visible in the sky, independent of the visibility of the sea horizon and without any elaborate calculations.

The speed of the ship through the water being measured every hour by the patent log, and the exact geographical position being determined by the solarometer every hour, the difference between the speed through the water and that made good over the ground will be the amount of current experienced.

It is difficult to estimate the importance of a full and complete investigation of this relationship of the barometer to the ocean currents. If the investigations demonstrate the exact character of the relations it may be possible for a mariner to see from one or more observations of the currents and the readings of the barometer the meteorologic conditions of a wide range over the ocean. Or, having barometer readings and meteorologic conditions, he may predict currents.

There is, of course, a certain amount of momentum to be overcome to cause a current, and an element of time would have to be considered, but investigation of the subject will doubtless reveal much of the mystery with which it is now connected.

To the science of meteorology the subject is one of the most important. The influence of the Gulf Stream and of the tropical waters which circulate with the Gulf Stream around the region of the almost permanent "high," upon the climate of Europe, and similar influences of like circulations on all five oceans all over the world, upon the climate of these regions are secondary to no other meteorologic phenomenon. Exact knowledge of the direction and strength of the ocean currents so determined will be of incalculable benefit to commerce and mankind.

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## 7.—PERIODIC AND NON-PERIODIC FLUCTUATIONS IN THE LATITUDE OF STORM TRACKS.

Dr. M. A. Veeder.

There are certain rearrangements in the distribution of atmospheric pressure of world-wide extent which, at times, continue throughout entire seasons, or even for series of years, and which, likewise at times, appear irregularly and sporadically at individual dates, which evidently must depend upon some cause capable of affecting the entire earth. The most prominent feature in such rearrangement is a displacement in latitude of the belts of anticyclones on each side of the equator with consequent deflection northward or southward, as the case may be, of the courses taken by

storms prevailing at such times. A very notable instance of one species of such displacement occurred in 1877–'78, when anticyclonic weather conditions were very persistent in low latitudes, as evidenced by the extraordinary extent and severity of the droughts which belted the entire earth in the equatorial regions. Coincidently, the diversion of storm tracks into higher latitudes was shown, especially by the phenomenal mildness of the winter seasons. Ten years later, in 1888–'89, there was a repetition of these same characteristic features dependent upon atmospheric distribution. In this instance the mildness of the winter season, particularly that of 1889–'90, seems to have extended even into the Arctic regions, causing floating ice to appear off the coast of Labrador and Newfoundland in great quantities throughout months in which it is rarely seen at all in that location. At the same time on the North American continent there was a marked deficiency in the severity and extent of cold waves, and storm tracks had their centers far north for extended periods. The same mildness appeared, likewise, in the northern parts of the eastern hemisphere, while in India, on the other hand, anticyclonic conditions predominated, there being "a general rise of abnormal barometric pressure for a considerable period * * * and scanty rainfall throughout the year." (*Nature*, June 5, 1890, p. 134.)

It is not within the province of a brief summary, such as the present, to do more than indicate leading features. Suffice it to say that the extraordinary persistence and extent of the distribution of the types of weather described in the years named is not only in strong contrast to average conditions, but is in still greater contrast to those prevailing in years when the divergence from the normal is in an opposite direction, anticyclones with greater dryness and stronger cold waves prevailing in higher latitudes, with corresponding displacement of cyclonic weather conditions into different and, for the most part, lower latitudes. The present year affords an example of this variety of divergence from the normal, both in this country and Europe, the winters in northern latitudes being distinguished by a severity in strong contrast to their mildness during the years previously named, and the areas distinguished by phenomenal droughts during the summer likewise being transferred to higher latitudes with coincident strengthening of the storms and hurricanes of low latitudes. In this connection it is worthy of note that what is thought to have been the lowest reading of the barometer ever recorded on the Atlantic was met with during a storm far south last December. So, too, the West Indian hurricane season now approaching promises to be severe. Coincidently, complaints of droughts are heard from the interior of the North American continent and from the north of Europe, Great Britain, especially, suffering severely. In order to bring out completely these contrasts in weather conditions

it would be necessary to consider in detail the effect of rearrangements in the distribution of atmospheric pressure upon rainfall, cloudiness, temperature, the direction and force of the winds, and the like, not only at different seasons of the year, but also in particular localities, which, manifestly, is a task of considerable magnitude. But without entering thus into detail it is sufficiently evident for the purposes of the present discussion that the distribution of cyclonic and anticyclonic weather conditions throughout the globe varies in different years in the manner which has been described. The broad features of these types of weather are readily distinguishable, both on land and sea and in summer and winter, under all the modifications which they thus undergo, so that their transference from one latitude to another can be traced with a good degree of confidence. Indeed such transference and localization of weather types through more or less extended periods is one of the most striking and familiar facts of meteorological observations.

In like manner, for brief intervals, there may intervene strongly marked but relatively transient divergences from the more persistent types of weather prevailing in the manner which has been described. Thus, upon some particular date, anticyclones may suddenly appear in higher latitudes than that which they had been accustomed to frequent for weeks or months preceding, and begin to move eastward with more activity and become stronger, the storms prevailing along their peripheries being modified likewise in respect to the courses which they pursue and the energy which they display. In such cases an impulse of some sort appears to have been imparted suddenly to the atmosphere, as a whole, the increased rapidity of eastward movement and intensification of storm action being apparent in the case of all cyclones and anticyclones prevailing at the time. Thus, instances have been noted in which storms in America and Europe, and off the coast of Japan, have acquired phenomenal intensity on the same day, constituting a well-defined period during which the energy of atmospheric movements was largely increased, anticyclones as well as cyclones being everywhere strengthened. In such cases as these there does not appear to be any delay, such as would be required if the increased activity displayed were dependent upon any slow process of warming up continents or seas. On the contrary the rearrangement in the distribution of atmospheric pressure (and incidental storm action) begins promptly and in such manner as to indicate that its origin is not dependent upon local terrestrial conditions, the part performed by such conditions being, apparently, to modify rather than originate the activities in question.

Thus, there are in general rearrangements in weather conditions so well defined, and upon such a large scale, that it is difficult to resist the conclusion that the atmosphere, as a whole, is under the control

of forces which have a common origin and which undergo variations at their very seat of origin. It would seem that it ought to be possible to determine to the best advantage the nature and mode of operation of such forces by a careful study of the instances in which the divergences from the normal are greatest. For several years the writer has been collecting information bearing upon this point, the outcome being the conclusion that the divergences in question must depend ultimately upon some form of solar variability, it being conceded on all hands that the sun is the great source of atmospheric control. As to the essential nature of this variability there is, however, a question. From current views respecting atmospheric control, we should naturally expect it to consist in variation in the sun's power of emitting heat. It is true that the weather conditions to which attention has been called present anomalies in respect to temperature, but these have reference to distribution rather than total amount. Thus, investigators using data from different parts of the earth have reached precisely opposite conclusions as to whether the sun is hotter or colder, and that, too, in the very years in which the departures from the normal of the kind indicated have been largest. In like manner, if averages are taken from a sufficiently large part of the earth, the variation of temperature from year to year is insignificant. So, too, the exposure of properly guarded thermometers to the direct rays of the sun in localities best adapted for such experiments, and under the most suitable conditions, has thus far given no evidence of variations in the sun's power of heat emission adequate to explain the facts to which reference has been made. It is a question, indeed, whether variation in the amount of heat falling upon the earth, as a whole, could produce the diversified local effects apparent and maintain them in the manner which actually appears. As a matter of fact, however, it is not yet known whether the sun is hotter or colder when freest from spots. The observations thus far made agree, however, in showing that the interposition of the atmosphere and its contents, and especially of the aqueous vapor which it contains, modifies the transmission and radiation of heat to such an extent that this and not solar variability may be the source of the changes in temperature distribution to which reference has been made. This being the case, these temperature anomalies are to be regarded as a mere incident in the rearrangement of atmospheric distribution rather than its cause. Thus it becomes necessary to look elsewhere than to variations in the heat-giving power of the sun for the source of atmospheric control. At this point and in this connection a relation of the weather conditions described to the distribution in latitude of the spots on the sun becomes of very great interest. It is found that the fluctuation in latitude of the belts of anticyclones on the earth and consequent diversion of storm tracks to which refer-

ence has been made follows, and is in direct proportion to a like change in latitude of the belts in which spots are most frequent on the sun; that is to say, in years in which spots appear in high latitudes, anticyclones do likewise, and *vice versa*. The transient and irregular deviations from this order constitute a case by themselves, and are to be studied in connection with the evidences of spasmodic outbreaks of solar activity on the one hand, or the fitful intervals of solar quiet on the other, which may interrupt the regular order of events in progress in any particular year or series of years.

The purpose of the present discussion is not to enter very much into the details of the evidence, which would be impossible within the limits assigned, but rather to indicate in a general way the nature of the problems involved as an incitement to further research. In the judgment of the writer, based upon such study as he has been able to make, there is ground for the belief that there are special forms of solar activity, not as yet perhaps fully identified, and certainly not as yet fully understood, which exercise powerful terrestrial effects independently of any perceptible attendant variation in the amount of solar heat falling upon the earth as a whole. In brief, these special solar activities appear to be of the nature of electro-magnetic induction, which may be attended by incidental heating effects, it is true, but these effects have a different distribution and depend upon conditions altogether unlike those which exist in the case of simple radiation from a source of combustion. Temperature distribution in the case of electro-magnetic induction depends upon the direction assumed by lines of force in a magnetic field, thus constituting a special form of radiant energy having characteristics essentially different from those manifest in the case of heat or light. From this point of view the manner of recurrence of auroras and magnetic storms and their relation to disturbances upon particular parts of the sun become an important subject of research, as affording the means of acquiring a knowledge of the limitations under which electro-magnetic inductive effects are conveyed from sun to earth. Especially important is the evidence that these effects are propagated at a definite angle, originating a periodicity of magnetic phenomena corresponding to the time of a synodic rotation of the sun, thus differing again from heat radiation which proceeds from the sun indifferently in every direction, and not at a certain angle exclusively. The determination of the solar meridian, or in other words, the angle at which the inductive effect is exercised is of the utmost importance.

The tables constructed by the writer for the purpose of such determination are very voluminous, covering nearly all lists of auroras in existence and very extensive records of magnetic storms and sun spots. The practical outcome is that the inductive effect proceeds

chiefly, if not exclusively from disturbed portions of the sun when at the eastern limb, and that such effect may at times originate thunderstorms instead of auroras, the substitution of one or the other of these two classes of phenomena depending apparently upon the location of the originating solar disturbance relative to the plane of the earth's orbit when at the eastern limb. There is evidence also of a terrestrial localization of these phenomena, dependent in part, apparently, upon the physical conditions existing at the time in various parts of the earth, and in part upon a concentration of effect at certain hour angles from the sun. Thus, there are diurnal maxima and secondary maxima both of thunderstorms and auroras, and the regions frequented by them have a belt-like distribution in magnetic latitude. From this it appears that the lines of force along which the inductive effect proceeds have a very definite arrangement, and that there are modifications of effect in particular portions of the field which these lines occupy, giving rise to thunderstorms instead of auroras, or *vice versa*, as the case may be. It would seem that the origin of the whole process is through electrification of particular portions of the sun's immediate surroundings through the agency of the turmoil of chemical and other activities due to the special violence of the eruptive forces there in operation, as compared with the rest of the sun, and that the inductive effect is propagated outward into space from these sections of the sun dynamically, or, in other words, in virtue of the motion of rotation.

The dynamic origination of electrical currents has been greatly familiarized of late by the commercial applications of the principle now in ordinary use for many purposes. Such origination depends upon a very different set of conditions from those involved in thermo-electric action to which these forms of solar activity have generally been referred heretofore. There is no evidence whatever that a magnetic storm is allied to or dependent upon heat radiations in any sense or to any extent whatever. Its method of origination and propagation is quite different in every respect, and any heating effects that may attend are incidental and remote. Thus there is a form of solar activity having its own distinguishing characteristics and existing as an entity by itself which deserves most careful study. The earth certainly is comprehended within the range of its operation, and it is altogether likely that the inductive effects thus experienced extend throughout the entire solar system, reaching every particle of meteoric dust and debris, and the vapors, if such there be, in interplanetary space, as well as the planets themselves. All these masses of matter charged up by induction exhibit permanent, subpermanent, and temporary effects, in accordance with which they act and react upon each other and likewise upon the sun itself, in conformity with the laws governing induction.

In the judgment of the writer it is the reactionary effect upon the sun itself of these inductive forces, causing rearrangements in the distribution of the vapors in its vicinity, as seen during eclipses, that determines the formation of spots and their varying location in latitude in a manner altogether similar to that seen in connection with the coincident changes in latitude of the belts of anticyclones on the earth. In any event, the fact that these rearrangements of the vaporous surroundings of sun and earth undergo similar variations in respect to location in corresponding years points to community of origin of these effects, and their evident relation to magnetic phenomena of the sort which has been described is such that it would seem not unwise to shift, if necessary, the point of view for the consideration of the entire subject, and to attack the problems at issue along the lines indicated in this discussion. This involves nothing less than a reconsideration of every fact and conclusion in respect to meteorological science from a standpoint altogether different from an assumed variability of solar heat.

It may be necessary to go so far as even to discard provisionally and tentatively the convection theory of the origin of storms, as ordinarily held, in order to determine fairly and completely the part which electro-magnetic induction of solar origin plays independently of heating effects. The distribution of temperatures, both in a horizontal and in a vertical direction in cyclones and anticyclones, and the velocity and extent of the associated wind movements, likewise in a horizontal and vertical direction, are not easy of explanation in conformity with the convection theory of the origin of storms. Thus, in tropical hurricanes, where the violence of the wind movement is extreme, the temperature gradient is small. Again, in the case of a severe storm remaining stationary like the New York blizzard, it would seem that the gravitational inflow of such enormous masses of air ought to involve a filling up process. Certainly, current views respecting the forces concerned in storm action do not give the slightest intimation as to where all the air goes in such a case as this.

In view of such facts as these, and without multiplying further illustrations, it would seem to be not only reasonable but necessary to institute an inquiry as to whether forces other than those heretofore taken into the account are not concerned. To this end especially important is the identification of the solar and other conditions on which auroras and magnetic storms depend, growing out of which there comes an apparent relation to thunderstorms. By the aid of the clue thus obtained it becomes possible to study the behavior of the atmosphere on critical dates, and during critical periods, whose identification is secured through a knowledge of these solar and associated conditions. As has been intimated throughout the course of the discussion the fluctuation in latitude of anticyclonic belts and

storm tracks both on the grandest possible scale, as affecting climate through series of years, and in individual instances on single dates, is most likely to afford an insight into the meteorological relations of electro-magnetic forces of solar origin. These forces certainly play a part in the economy of the solar system, and there are indications that this part is far more important than has heretofore been supposed.

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## 8.—NORTH ATLANTIC CURRENTS AND SURFACE TEMPERATURES.

Lieut. A. HAUTREUX, French Navy.

It is impossible to speak of meteorology or the physical geography of the sea without the spirit of the immortal name of Lieut. Maury. He it was who systematized the best manner of making observations and enunciated the principles and general laws of the circulation of the atmosphere and the oceans to the scientific world. In his school this science has been studied, and especially in the United States, where it has been most developed on land and sea.

It is in that vast country, washed by two oceans, possessing both tropical and polar climates, the highest mountains and most extensive plains, rainless deserts and the most fertile regions, with coasts washed by the greatest oceanic river in the world and annually receiving glacial tributes from Greenland—it is there where the elements of heat and cold, dryness and moisture, rage and produce with greatest force the phenomena caused by the conflict. There the science of meteorology, based upon actual observations, has made the greatest progress. There, also, the public is most promptly notified and warned of meteorological disturbances, and measures taken to prepare for them.

The grand laws of meteorology, which Maury so admirably reduced to harmony from phenomena often of the most fleeting character and complicated by local anomalies, have by experience been demonstrated in detail to be of great service for the security of navigation.

Some of these points, especially those relating to the currents and surface temperatures of the North Atlantic, we will proceed to investigate in this paper.

The scientific expeditions so wisely directed by the governments of the United States, England, Germany, and France for the physical examination of the ocean, in connection with the deep-sea soundings for the trans-Atlantic submarine cables, have covered the sea so thoroughly with a net of observations that scarcely any important feature has escaped their investigations. They have established that no part of the ocean is at rest, but that the entire mass of the ocean from the surface to the profoundest depths is constantly in motion

to re-establish the equilibrium destroyed by the action of tides, the pressure of winds, and the changes of temperature and density.

The waters of the ocean are subjected to a double circulatory movement, vertical and horizontal.

The vertical motion is determined by the study of the submarine isotherms. The cold polar waters sink below the waters of temperate zones, and ascend toward the surface in tropical zones, where they cause great evaporation.

The horizontal circulation on the surface was known to ancient navigators who utilized or defied it. This is found in all oceans more or less permanent or intermittent and its most energetic actions are produced near the coasts by the tidal action and at sea by the effect of the wind.

The action of the wind upon the surface water is most effective; it produces the waves and carries the molecules of water to leeward, and often in a *cul de sac* raises the surface many meters high, and under continuous action often stops the tides.

Especially in the Atlantic the continuous action of the northeast and southeast trades forces the inter-tropical waters westward, where the configuration of the coast at the mouth of the Amazon River deflects the waters to the Windward Islands, through the numerous passages between these islands into the Caribbean Sea. The barrier formed by the large islands of Puerto Rico, Haiti, and Cuba, compels the accumulating waters to enter the Gulf of Mexico, whose surface level is thereby raised, and then finds its only exit between Cuba and Florida. Thence these waters meet the coral banks of the Bahamas and form an enormous river with a rapid current which follows the coast of the United States to Cape Hatteras, where it is known as the Gulf Stream. Thence deflected to pass south of Newfoundland and the Grand Banks, it opens out like a fan and spreads over the surface of the North Atlantic, with a loss of its speed and much of its distinctive character.

The name of Lieut. Pillsbury is forever associated with other enterprising scientists of the United States Government who have so completely investigated this remarkable current.

After the waters of the Gulf Stream spread out over the surface the axial direction follows that of a great circle which passes north of the Azores and reaches the coast of Portugal. Here two causes operate to influence the current. During the summer the north winds in prolongation of the northeast trades along the Portugal coast brush these waters to the southward, where they come under the influence of the northeast trades and the region of the Equatorial Current; during the winter the southwest winds push these waters from the mid North Atlantic to the northeast to the shores of Ireland and Norway.

There are besides the Gulf Stream other currents which are recognized as permanent and have certain general features, such as the Labrador Current, caused by the melted snow and ice of polar regions, and the Counter Equatorial Current, produced by the southwest winds of the coast of Africa.

These currents have been found by observations of navigators and from the drift of floating objects, such as ice, wood, bottles, and hulls of vessels. The observations conducted for the Pilot Charts, published by the Hydrographic Office of the U. S. Navy, at Washington, D. C., have been of great importance. These show the precise resultant of the complicated causes to which a floating vessel is subjected. If the hull of a derelict vessel, immersed 6 to 8 meters in the water without exposing to the wind more than a portion of its dismantled hull, should for several days in a month drift in a certain direction it is evident that the mass of water in which it floats must have moved in the same direction.

There are other surface movements of the sea which are designated as permanent currents, but which facts show are subject to important and unforeseen variations. An examination of the Pilot Charts will show several examples.

We beg the reader carefully to examine these charts, and especially certain supplements which have been published by the Washington Hydrographic Office, viz: "The Drift of Bottle Papers," July, 1891; "The Derelict Schooner White," February, 1889.

We will proceed to investigate the following: The Norwegian Current, the Rennell Current, the currents of the coast of Portugal and the west coast of Africa, the currents of the Sargasso Sea, and the temperatures of the sea from Bordeaux to the La Plata River, from Bordeaux to New York, and in the Bay of Biscay.

### THE NORWEGIAN CURRENT.

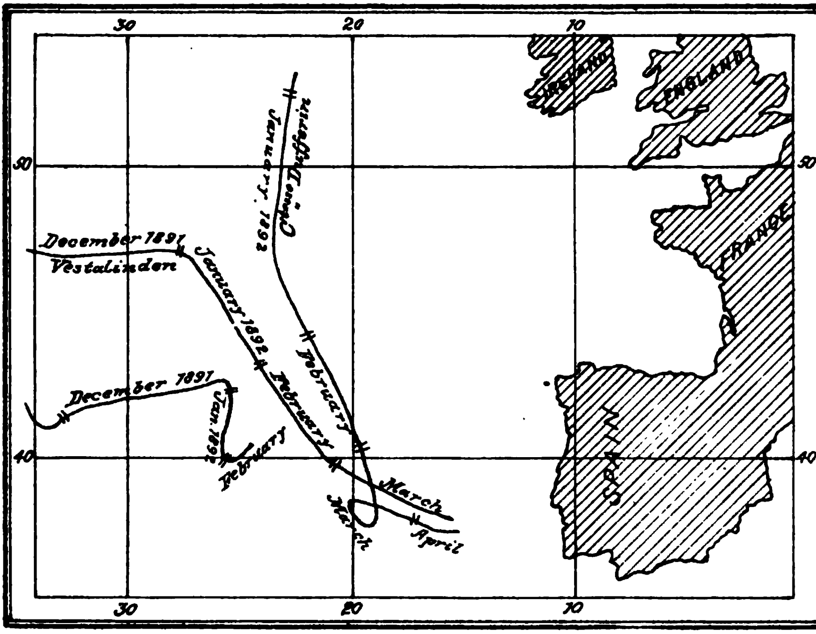
In summer the Atlantic, north of the Azores, does not appear to be so much under the influence of the Gulf Stream, and yet in that season the stream has its greatest extension toward the north, a fact which is demonstrated by the tracks of the derelicts *Twenty-one Friends*, in July, August, and September, the *White*, in June, July, August, and September, the *E. Davis*, in August and September, and the *Hunt*, in July.

In the season when the southwest and west winds prevail the waters are pushed northeast and east. The fact is shown by the drift of numerous derelicts published on the Pilot Charts, and of the drift of bottle papers in the special supplement of the Pilot Charts, 1891–'92. Nevertheless, even in this season, the condition of the barometric pressure on the Atlantic prevents the westerly winds from allowing these waters to reach the shores of Europe. The surface waters do

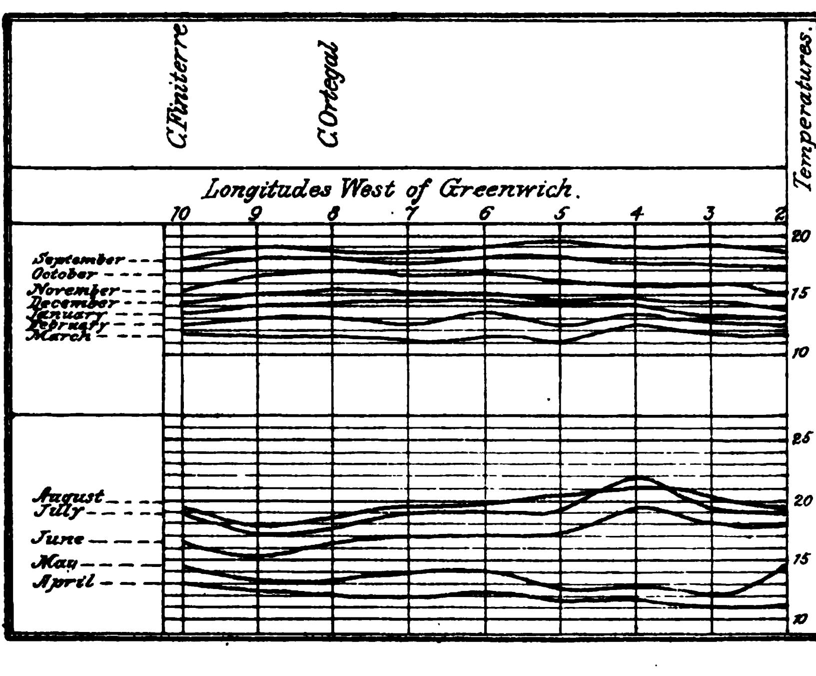
## Currents of the North Atlantic in 1892.

Paths of drifting wrecks.

**Plate VIII.** *Hautreux.*




## Temperature of water in the Bay of Biscay.



not always follow their usual course, as is shown by the tracks of the derelicts *Countess Dufferin*, *Vestalinden*, and *Daphne*, which drifted toward the south and south-southeast. (See Plate VIII.) For during these months anticyclones covered the North Atlantic, and rare depressions traversed the European coasts, traveling from north-northwest to south-southeast.

These facts appear to prove to us that the wind predominates in giving direction to the surface waters of this part of the Atlantic. Fine weather and light winds prevailed during the summer, and the drifting derelicts show that then the surface waters are most frequently transported with continuous regularity. During the season when strong winds blow from the south and west the waters are forced to the north and east, but whatever may be the cause, those strong west winds fail to make the derelicts always follow the impulse they receive.

Drifting bottles launched northwest of the Azores by the yacht *L'Hirondelle*, which were recovered in the Azores Islands, clearly prove that this current has not the degree of permanence which has been ascribed to it as a branch of the Gulf Stream.

This current is absolutely dependent upon the surface winds which in summer force the waters of the mid-Atlantic toward the European coasts with a temperature always above 10° C.

### CURRENTS IN THE BAY OF BISCAY.

The so-called Rennell Current is represented as a derivative of the Gulf Stream which meets the coast at Cape Finisterre and then divides into two branches, one of which flows south along the coast of Portugal, the other enters the Bay of Biscay, following the north coast of Spain, thence flows north and northwest along the French coast and is lost in the general currents of the channel.

The drifting derelicts are again quoted to present facts not in accord with this theory, viz: *Twenty-one Friends*, in 1886; *Stormy Petrel*, in 1887; *Emilie* and *Petty*, in 1888; *Atlas*, *Carrier Dove*, and *Herman*, in 1890; schooners *Ryerson* and *Helios*, in 1891. (See Plate VIII.) Besides, in the drift of bottle papers, Nos. 12, 17, 29, and 30 have also followed anomalous directions. (See Plate IX.)

The Prince of Monaco, after his admirable experiments in the yacht *L'Hirondelle*, concludes that the currents in the Bay of Biscay are contrary to the Rennell Current. He estimates that the waters from the Gulf Stream divide at Ushant; one branch goes up the channel and the other enters the Bay of Biscay, flowing southeast, then south along the coast of France, and finds outlet westward along the north coast of Spain. If these two theories are correct, we have thought that there might be a point on the French coast in the vicinity of Arcachon where currents would be found regularly setting

north and south. This must appear logical on account of the uniform regularity of the coast line there, so that this important sheet of water is not influenced by eddies such as would be found upon an indented shore.

There is, fortunately, at Arcachon a fishing industry having five steamers, under the direction of Mr. H. Johnson, who readily consented to assist our investigations and ordered bottle papers to be launched for this purpose. The captains of these vessels made the following reports, which have been forwarded to the Hydrographic Office at Washington, D. C.

Extract from the report of Capt. Pateau:

The currents are not regular. They are caused by the wind; with north winds the currents set south, and with south winds they set north. At times there is no current with the wind east offshore. In winter the currents are stronger than in summer.

Extract from the report of Capt. Durand:

I have always noticed that when the wind is south or southwest the currents set north along the coast of France, but with the wind northeast or northwest they set south toward the bottom of the bay, and thence flow west along the coast of Spain, with a velocity proportional to the strength of the wind and its continuance.

Extract from the report of M. Silhouette, of Biarritz:

Formerly many small trading vessels frequented Bayonne and were often lost. The vessels were carried perpendicularly to shore, head on. Subsequently their sterns were carried south by the current from the north.

All these reports agree that the currents in the Bay of Biscay are absolutely dependent upon the prevailing winds.

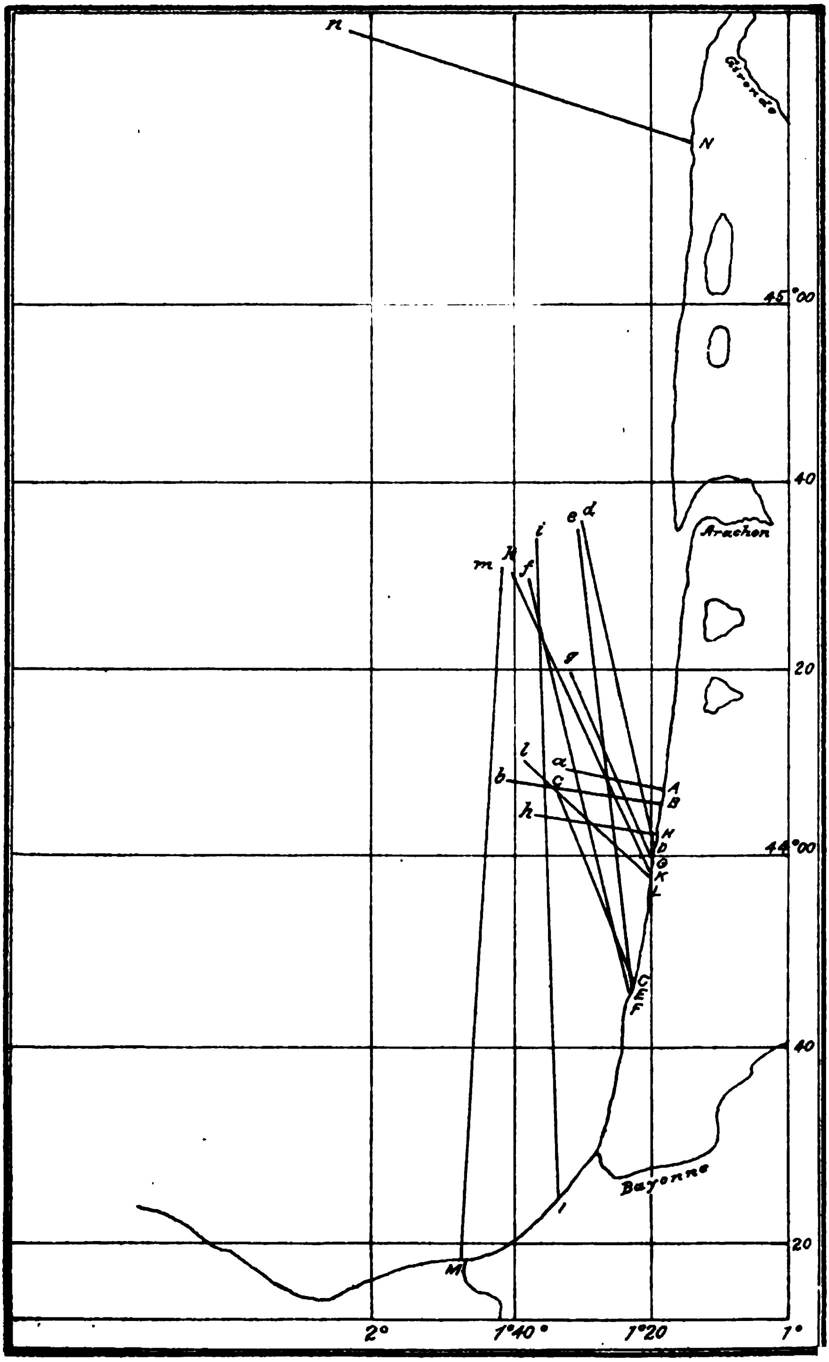
In order to confirm these reports we have, during June and July of this year, thrown overboard a number of bottles, three-fourths full of water, attached to floats by a line two fathoms long. The length of the line being such that the bottles might be readily recovered on the coast at low tide. These bottles were thrown overboard 12 to 30 miles from the coast in depths of 40 to 60 fathoms.

The results of these experiments were collected and sent to the Hydrographic Office at Washington, D. C., which office is hereby requested to communicate them to the Congress. The experiments were commenced on May 25 and continued at the rate of three or four every week. The last one, recovered on July 3, had been thrown overboard on June 21, by the steamer *Oceanique*. Out of the eighteen or nineteen bottles thrown overboard, thirteen were recovered—a large proportion. (See table on page 198 and Plate IX.)

The currents observed on board the vessels where the bottles were thrown overboard were weak and the general set was south-southwest. The bottles were adrift in the water for an average period of fourteen days, and the resultant direction of their drift was to the south-southeast. Not one bottle was found north of the place whence it was set adrift. This is contrary to the theory of the Rennell Current.

Drifting bottles, June, 1893.

**Plate IX.** *Hautreux.*



North of the region observed the prevailing wind during the period from May 25 to June 22 was toward the southwest, while south of that region, near Biarritz, the mean direction was toward the east-southeast. The resultant direction of the drift of the bottles was south-southeast, which direction is the mean resultant of a drift first to the southwest and then east-southeast. The velocity of the drift, derived by dividing the distance drifted by the number of days afloat, was for twenty-four hours a maximum of 4.2 miles, a minimum of 1.4, and a mean of 2.5.

Upon examining the sketch it will be seen that the bottles may be classed in two groups—A, B, H, L, and N, which drifted east-southeast, and C, D, E, F, G, I, K, and M, which drifted toward the south and south-southeast.

There are two charts of the currents of the Bay of Biscay, one by G. Simart, Lieutenant, French Navy, published in 1889, and one by the Prince of Monaco, 1892. In the Simart charts the currents of the Bay of Biscay are laid down as setting south at the rate of 4 to 5 miles in twenty-four hours. In the chart of the Prince of Monaco, the currents are laid down as setting east at the rate of 6.6 miles for twenty-four hours. The two directions are at right angles to each other. Our experiments do not reconcile the difference. The tracks of shortest periods are those of the Prince of Monaco, the longer tracks are those on the chart of Lieut. Simart. But there is one fact to be remarked that on the chart of the Prince of Monaco the shortest drift tracks, considered as best indicating the direction and set, were made during September, October, November, and December, 1886. In this year the autumn was characterized by excessive rains in the Bay of Biscay. The records of the observatory at Bordeaux show a rainfall for September of 102 mm. and October, 205 mm. This is double the mean rainfall. This excessive rainfall is certain proof of the frequency and violence of the west winds in the fall of 1886. It is probable, therefore, that the effects of the wind transporting the water caused the current to set east at the rate of 6.6 miles per twenty-four hours, a rate three times as fast as was experienced in our experiments during June of this year.

Our results were obtained during a period in which fine weather prevailed, and they show that floating bodies drift to the east and south of the point of departure during the month of June, and that they are pushed with a slow and irregular velocity. A set of 2.5 miles in twenty-four hours can scarcely be called a current.

These facts demonstrate that the Rennell Current has neither the permanence nor the velocity with which it is credited, and that at least during the summer, along the French coast, the current sets more frequently south than north. It is also seen that it sets toward the beach, a feature most dangerous to vessels. This explains the

dangerous character which has always been accredited to the Bay of Biscay. No sailing vessel can beat off the coast while the winds and currents both set her on. These facts show that the wind is the preponderating factor in causing the currents whose direction and set are often modified by the configuration of the coast. They prove also that near the coast there is a surface movement which is dangerous to navigation and should be studied carefully.

*Table of drifting bottles near Arcachon.*

| Thrown into the sea. | | | | Recovered. | | | Drift. | | |
|---|---|---|---|---|---|---|---|---|---|
| Designating letter. | Latitude. | Distance off-shore. | Current. | Latitude. | Longitude, Greenwich. | Distance. | Direction. | Days. | Rate of drift. |
| | ° ′ | *Miles.* | | ° ′ | ° ′ | *Miles.* | ° | | *Miles.* |
| A | 44 12 | 10 | SW. | 44 08 | 1 20 | 11 | S. 70 E. | 5 | 2.2 |
| B | 44 11 | 18 | SSE. | 44 07 | 1 20 | 20 | S. 78 E. | 9 | 2.2 |
| C | 44 12 | 10 | SW. | 43 44 | 1 24 | 29 | S. 18 E. | 13 | 2.2 |
| D | 44 40 | 10 | NW. | 44 00 | 1 21 | 42 | S. 10 E. | 19 | 2.2 |
| E | 44 40 | 10 | NW. | 43 44 | 1 24 | 56 | S. 5 E. | 19 | 2.9 |
| F | 44 30 | 14 | NNE. | 43 43 | 1 24 | 48 | S. 15 E. | 17 | 2.8 |
| G | 44 24 | 12 | NNE. | 43 57 | 1 28 | 30 | S. 20 E. | 17 | 1.7 |
| H | 44 07 | 12 | SSW. | 44 02 | 1 21 | 13 | S. 70 E. | 9 | 1.4 |
| I | 44 36 | 15 | NNE. | 43 26 | 1 33 | 68 | S. 3 E. | 16 | 4.2 |
| K | 44 30 | 18 | SW. | 43 56 | 1 28 | 38 | S. 25 E. | 15 | 2.5 |
| L | 44 13 | 14 | SW. | 43 55 | 1 28 | 22 | S. 34 E. | 9 | 2.4 |
| M | 44 30 | 20 | SW. | 43 22 | 1 54 | 72 | S. 4 W. | 19 | 3.8 |
| N | 45 32 | 34 | SW. | 45 20 | 1 12 | 36 | S. 70 E. | 13 | 2.8 |

## CURRENTS OF PORTUGAL AND WEST COAST OF AFRICA.

For this the observations of the steamers of the Messageries Maritimes, taken from time to time for six years with about four each month, are considered in detail. These steamers ply along the coast of Portugal and Africa as far as the Cape Verde Islands. The currents have not the permanence to which they are credited, but in each season there are certain features.

*Winter.*—Along the coast of Portugal the current sets north and north-northwest; from Madeira to the Canary Islands the current sets north-northeast, and from the Canary Islands to Dakar the current sets west-southwest. The Counter Equatorial Current sets southeast.

*Summer.*—Along the coast of Portugal the current sets south to south-southeast. From Madeira to the Canaries the current sets south-southwest. From the Canaries to Dakar the current sets south-southwest. The Counter Equatorial Current sets east. A velocity of about one mile per hour has been found between the Canaries and Dakar and between the equator and Pernambuco.

The difference in direction in summer and winter corresponds with the changes in the direction of the prevailing winds in these regions in these seasons. During the winter southwest winds are frequent between Madeira and Cape Finisterre, and they force the water to leeward to the north. In summer northerly winds prevail and force

the water south. Near Dakar, in the period of the southwest monsoons of the coast of Africa, the Counter Equatorial Current carries warm water ashore near the Arquin Bank, Cape Blanco.

It is to be noticed that in the trade-wind regions the westerly component of the current is always greater than that of the wind.

### THE SARGASSO SEA.

Southwest of the Azores the waters of the Atlantic form a large whirlpool analogous and corresponding to the general circulation of the surface winds. The movement is demonstrated by the drifts of the derelicts *Telemach*, *Drury*, *Wyer G. Sargent*, and *Fannie E. Wolston*. The diameter of the curves of these tracks is from 350 to 400 miles.

These drifts are evidently the resultant effects of the surface winds. For in this sea the drifts to the westward took place from July to November during the period when the trades extended farthest north, and to the north and east during the winter months, when the predominant winds in that region were south and west. The agreement in the directions of the winds and the oceanic surface drift is therefore complete.

### CURRENTS BETWEEN BERMUDA AND THE WEST INDIES.

All charts show in this region a prolongation of the equatorial drift toward the north, and a large mass of water passing north of the West Indies and joining the right side of the Gulf Stream.

Notwithstanding this the Pilot Charts show that the derelicts *Vincenzo Perrota*, *Ida Francis*, *Mary Douglass*, and *Rita* were for several months in that vicinity without being drifted by that current. In the chart, "Drift of Bottle Papers" (No. IX), bottles Nos. 5, 88, 106, and 129, also show that if such a current exists at times it has not the permanence attributed to it by the charts. It can be said that the drifts of the floats are directly contrary to the current indicated on the charts.

From all these observations we may conclude that the wind is the great cause for most of the surface movement of the sea. Its action causes the deviations from the displacement due to the tides and glacial discharges.

### TEMPERATURE OF THE SEA BETWEEN BORDEAUX AND LA PLATA.

The study of the submarine temperatures has revealed the laws of the vertical circulation of waters. In examining the submarine isotherms along a meridian one is at once struck by the marked inclination of these isotherms near shoals, the horizontality of the lines in temperate zones, and their rise toward the surface in warmer regions.

It is difficult to explain why the isotherm of 7° to 10° C., after descending to a depth of 1,500 to 2,000 meters near the Canaries,

should rise to nearly 200 or 300 meters below the surface, contrary to all the laws of gravity and to the movement of the waters by the surface winds. It must surely be due to the tropical evaporation and the necessity of replacing the equatorial waters that the vertical movement acts like a vast pump. If there is one place where this movement is specially emphasized, we believe such a place exists in the vicinity of Cape Blanco, Africa, near Arquin Bank.

The observations of temperature of the mail steamers of the Messageries Maritimes on their voyages between Bordeaux and the La Plata (see table below) show that the temperature between Lisbon and the Canaries increases regularly by 4° to 6° C., and that this increase augments most rapidly in November and least in March.

*Temperature of the sea between Bordeaux and the La Plata.*

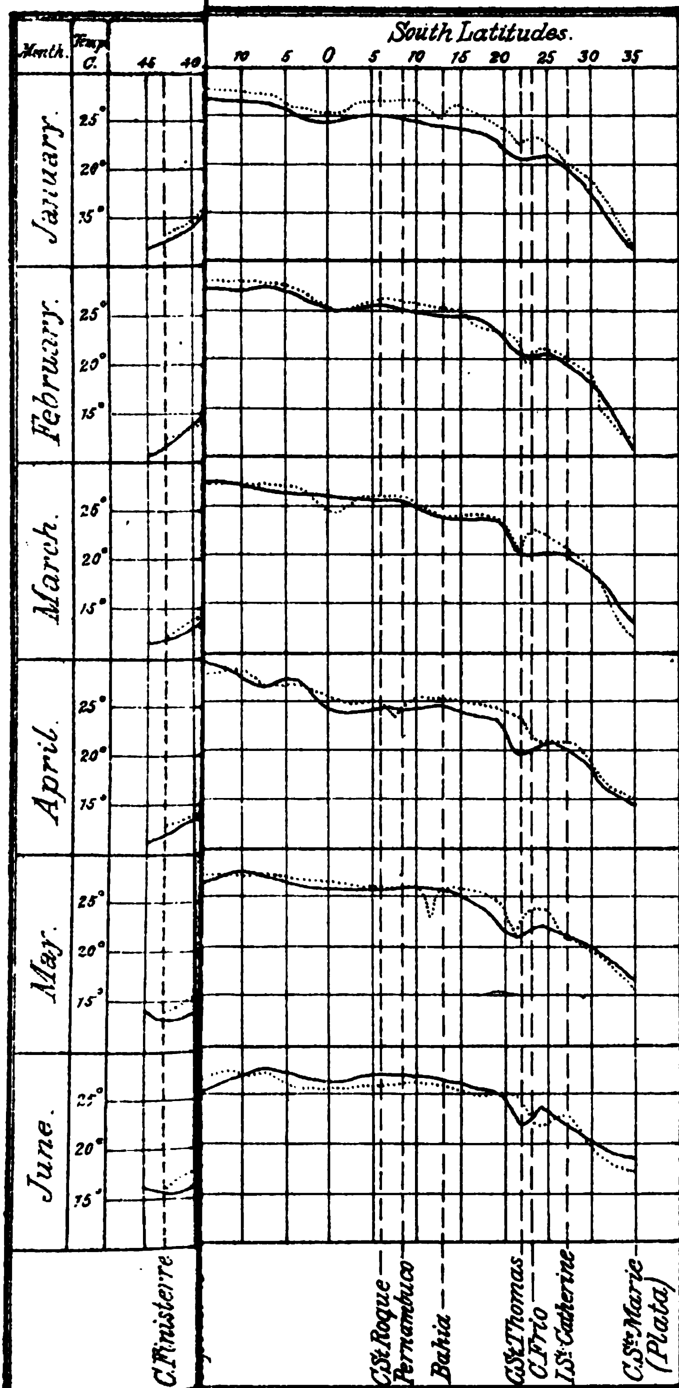
| Longitude west of Greenwich. | Latitude. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ° ′ | ° ′ | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° |
| 4 00 | N. 45 00 | 12.0 | 11.0 | 12.0 | 12.0 | 14.5 | 16.5 | 17.0 | 19.0 | 19.0 | 17.0 | 14.5 | 13.0 |
| 9 30 | N. 42 30 | 13.0 | 12.3 | 12.5 | 12.2 | 13.4 | 15.6 | 16.4 | 17.9 | 17.4 | 14.0 | 13.4 | 13.0 |
| 9 30 | N. 40 00 | 14.8 | 14.6 | 13.7 | 14.1 | 14.6 | 16.5 | 16.9 | 18.1 | 18.6 | 17.5 | 15.7 | 14.0 |
| 10 00 | N. 37 30 | 16.0 | 15.3 | 15.0 | 15.0 | 15.5 | 18.0 | 17.6 | 20.2 | 20.0 | 20.2 | 18.3 | 16.0 |
| 11 00 | N. 35 00 | 18.0 | 16.3 | 16.0 | 16.0 | 17.5 | 18.7 | 19.8 | 21.7 | 21.2 | 21.3 | 19.5 | 18.0 |
| 12 30 | N. 32 30 | 18.0 | 17.0 | 17.5 | 17.0 | 18.0 | 19.5 | 20.4 | 22.1 | 21.7 | 21.0 | 20.6 | 18.6 |
| 14 00 | N. 30 00 | 18.5 | 17.5 | 17.7 | 17.6 | 19.0 | 20.0 | 20.7 | 22.2 | 22.7 | 22.0 | 21.1 | 19.4 |
| 15 00 | N. 27 30 | 18.6 | 17.5 | 18.5 | 18.5 | 19.8 | 20.5 | 21.0 | 22.8 | 24.0 | 22.5 | 22.1 | 20.0 |
| 16 30 | N. 25 00 | 18.5 | 18.0 | 19.0 | 19.6 | 19.8 | 20.1 | 20.6 | 22.2 | 21.3 | 22.0 | 22.6 | 20.0 |
| 17 30 | N. 22 30 | 17.9 | 17.5 | 18.0 | 19.0 | 19.2 | 18.9 | 19.9 | 21.5 | 20.4 | 21.3 | 23.1 | 20.0 |
| 18 00 | N. 20 00 | 17.3 | 18.5 | 20.0 | 17.4 | 17.7 | 17.5 | 22.4 | 24.5 | 25.0 | 20.8 | 21.0 | 22.0 |
| 18 00 | N. 17 30 | 19.8 | 19.0 | 21.3 | 19.2 | 20.4 | 22.2 | 25.8 | 25.6 | 27.0 | 26.8 | 22.7 | 24.4 |
| 18 00 | N. 15 00 | 22.6 | 22.1 | 20.5 | 20.5 | 23.2 | 25.4 | 27.0 | 27.4 | 27.2 | 29.5 | 26.4 | 25.1 |
| 19 00 | N. 12 30 | 25.3 | 23.7 | 23.0 | 24.0 | 25.1 | 27.8 | 26.3 | 27.1 | 28.0 | 28.2 | 26.9 | 25.8 |
| 21 00 | N. 10 00 | 26.1 | 25.0 | 25.0 | 25.4 | 26.1 | 27.8 | 26.4 | 27.0 | 27.0 | 28.0 | 27.3 | 27.1 |
| 23 00 | N. 7 30 | 26.9 | 27.0 | 26.0 | 27.5 | 27.1 | 27.3 | 26.3 | 27.4 | 27.0 | 26.6 | 27.0 | 27.4 |
| 24 30 | N. 5 00 | 26.6 | 27.0 | 27.0 | 28.5 | 27.5 | 27.8 | 26.0 | 27.0 | 26.6 | 27.4 | 26.7 | 27.5 |
| 26 30 | N. 2 30 | 26.4 | 27.0 | 27.8 | 26.7 | 28.0 | 28.5 | 26.0 | 25.0 | 25.4 | 26.7 | 26.2 | 26.7 |
| 28 00 | 0 00 | 25.9 | 26.7 | 27.0 | 26.1 | 27.7 | 28.0 | 25.4 | 25.0 | 25.4 | 25.9 | 26.0 | 26.1 |
| 29 30 | S. 2 30 | 26.0 | 26.7 | 27.5 | 27.3 | 27.1 | 27.0 | 25.4 | 25.0 | 25.5 | 25.5 | 25.9 | 26.1 |
| 31 30 | S. 5 00 | 26.4 | 26.5 | 27.9 | 27.4 | 27.8 | 26.5 | 25.7 | 25.9 | 25.6 | 25.2 | 25.7 | 26.4 |
| 33 00 | S. 7 30 | 26.7 | 27.0 | 27.9 | 27.0 | 27.5 | 26.0 | 25.8 | 25.7 | 25.8 | 25.5 | 25.7 | 26.8 |
| 34 30 | S. 10 00 | 26.9 | 27.0 | 27.6 | 27.0 | 27.1 | 25.8 | 25.3 | 25.3 | 25.3 | 25.4 | 25.5 | 26.7 |
| 36 00 | S. 12 30 | 26.7 | 27.0 | 27.3 | 27.1 | 26.3 | 25.8 | 24.7 | 24.9 | 24.5 | 25.4 | 25.5 | 26.3 |
| 37 00 | S. 15 00 | 26.4 | 26.6 | 27.3 | 26.7 | 25.7 | 25.5 | 24.5 | 24.5 | 24.0 | 23.5 | 25.4 | 26.3 |
| 38 00 | S. 17 30 | 25.6 | 26.5 | 27.1 | 26.6 | 25.7 | 25.0 | 24.2 | 24.2 | 24.1 | 23.5 | 24.8 | 25.9 |
| 39 00 | S. 20 00 | 25.6 | 26.5 | 26.5 | 26.2 | 25.3 | 24.5 | 23.1 | 23.5 | 23.3 | 23.4 | 21.9 | 25.4 |
| 40 00 | S. 22 30 | 23.3 | 21.0 | 24.5 | 23.0 | 21.8 | 20.0 | 20.0 | 20.5 | 20.2 | 19.3 | 20.4 | 21.8 |
| 45 00 | S. 25 00 | 25.5 | 25.3 | 26.5 | 24.5 | 24.0 | 23.5 | 21.2 | 21.1 | 21.0 | 21.2 | 22.9 | 23.6 |
| 47 00 | S. 27 30 | 24.5 | 25.5 | 27.0 | 24.0 | 24.0 | 18.3 | 20.6 | 20.1 | 20.3 | 21.0 | 22.2 | 22.8 |
| 49 00 | S. 30 00 | 24.0 | 25.0 | 25.0 | 22.3 | 22.0 | 16.5 | 18.6 | 18.1 | 18.9 | 18.7 | 21.1 | 21.0 |
| 51 30 | S. 32 30 | 22.4 | 23.5 | 23.0 | 20.8 | 20.0 | 13.5 | 14.2 | 15.1 | 16.1 | 17.4 | 19.4 | 20.5 |
| 54 00 | S. 35 00 | 19.5 | 20.5 | 19.5 | 18.8 | 17.5 | 12.0 | 11.6 | 11.0 | 13.4 | 15.0 | 16.4 | 19.4 |

From the Canaries to the Arquin Bank the temperature falls from 2° to 2½° C. from April to November. The fall is less marked but is found also during the winter months. The center of the thermal depression oscillates between N. 20° and N. 22°, it runs near the coast on the level of the peninsula of Cape Verde, and it is deflected at the time the currents change direction.

From the Arquin Bank to Dakar there is a sudden thermal rise of 8° to 9° C. in September and October; the rise is less in March and April. The sharp bend in the isotherms has also been established by

the years 1879 and 1880.

Plate X. *Hautreux.*

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the exploring expedition of the *Talisman*. On this vessel it was observed that the density of the surface waters was only 1,024.8 or 3.0 less than that of neighboring waters, and also that this diminution in the saltness exists in deep layers when the temperature is as low as 7° C.

This low density accompanied by low temperature in this warm region proves decidedly the polar source of these waters and their rise to the surface. The color of this water is also different, being green while the neighboring trade-wind water is blue. The depths reach 2,200 meters.

The observations on the mail steamers show another point of thermal depression and rise to the surface. This is near Cape Frio. In the warm season when the rainfall is most marked the thermal depression is about 3° or 4° C.

### FROM BORDEAUX TO NEW YORK.

The Bordelaise mail steamers plying between Bordeaux and New York have willingly given me the results of their observations for several years, 1882 to 1887. The route of these steamers crosses the fortieth meridian in N. 47° 30′ and passes the southern extremity of the Banks of Newfoundland.

In the curve of these isotherms one is at once struck by their irregularities between the fortieth meridian and New York, and by their absolute uniformity between that and the mouth of the Gironde.

*Temperature of the sea from Bordeaux to New York.*

| North latitude. | Longitude west of Greenwich. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ° ′ | ° ′ | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° |
| 46 00 | 8 00 | 12.5 | 11.5 | 11.5 | 13.0 | 13.5 | 16.0 | 17.5 | 18.0 | 18.0 | 16.0 | 14.0 | 13.0 |
| 46 00 | 13 00 | 12.5 | 12.0 | 12.0 | 13.0 | 13.5 | 16.0 | 17.5 | 18.0 | 18.0 | 16.0 | 14.0 | 13.0 |
| 47 00 | 18 00 | 12.5 | 12.0 | 12.5 | 13.0 | 13.5 | 16.0 | 17.5 | 18.0 | 18.0 | 16.0 | 14.0 | 13.0 |
| 47 00 | 23 00 | 13.0 | 12.5 | 12.5 | 13.5 | 14.0 | 16.0 | 17.5 | 18.0 | 18.5 | 16.1 | 14.5 | 13.5 |
| 47 00 | 28 00 | 13.5 | 12.5 | 13.0 | 13.5 | 14.0 | 15.5 | 18.0 | 19.0 | 19.0 | 16.5 | 13.5 | 13.5 |
| 47 00 | 33 00 | 14.0 | 12.5 | 13.0 | 14.0 | 14.0 | 16.0 | 18.0 | 20.0 | 20.0 | 17.0 | 14.0 | 14.0 |
| 46 00 | 38 00 | 14.0 | 12.5 | 13.0 | 15.0 | 14.0 | 18.0 | 18.0 | 20.0 | 20.0 | 18.0 | 14.0 | 14.0 |
| 45 00 | 43 00 | 14.0 | 14.0 | 14.0 | 15.0 | 14.0 | 20.0 | 21.0 | 23.0 | 23.0 | 20.0 | 16.0 | 16.0 |
| 44 00 | 48 00 | 10.0 | 14.5 | 15.0 | 8.0 | 8.0 | 15.0 | 16.0 | 18.0 | 15.6 | 11.0 | 11.0 | 10.0 |
| Grand Bank | 50 00 | − 1.0 | 0.0 | 0.0 | 1.0 | 6.0 | 8.0 | 11.0 | 14.0 | 11.0 | 8.0 | 6.0 | 4.0 |
| 43 00 | 53 00 | 5.0 | 5.0 | 10.0 | 13.0 | 16.0 | 21.0 | 19.0 | 21.0 | 17.0 | 16.0 | 10.0 | 9.0 |
| 42 00 | 58 00 | 10.0 | 15.0 | 15.0 | 17.0 | 17.0 | 21.0 | 22.0 | 24.0 | 21.0 | 21.0 | 17.0 | 17.0 |
| 41 00 | 63 00 | 8.0 | 11.0 | 13.0 | 15.0 | 15.0 | 20.0 | 22.0 | 24.0 | 22.0 | 25.0 | 17.0 | 16.0 |
| 41 00 | 68 00 | 6.0 | 7.0 | 6.0 | 5.0 | 9.0 | 14.0 | 18.0 | 21.0 | 19.0 | 18.0 | 11.0 | 10.0 |
| 40 00 | 73 00 | 4.0 | 4.0 | 4.0 | 5.0 | 7.0 | 11.0 | 19.0 | 19.0 | 18.0 | 16.0 | 13.0 | 11.0 |
| The curve | | 12.0 | 11.0 | 11.0 | 13.0 | 14.0 | 17.0 | 19.0 | 20.0 | 19.0 | 17.0 | 15.0 | 13.0 |

Therefore, these thermal differences near the American coast prove the sources of the waters to be different, while the main currents that reach the European shores are more stationary and are pushed and mixed by the winds.

### BAY OF BISCAY.

In a region so contracted there can not be great thermal differences. Such small differences as exist are evidences of the movement of the waters in that great bay. We have the observations of the mail steamers, from time to time, for a distance of about 50 miles from the mouth of the Gironde to Cape Ortegal. A study of the lines of isotherms, month by month, shows that in the months of June, July, and August there is, along the fourth meridian west of Greenwich, a mass of water about 100 miles wide, whose temperature is about 2° or 3° C. higher than that of the French coast waters, and that from this point to Cape Ortegal the temperature gradually falls in the summer months until it is 2° C. lower than that of the coast waters. (See tables and plate.)

This state of things indicates that the Rennell Current does not exist during the summer months as stated on the chart. To supply this mass of warm water along the fourth meridian, one can only find an oceanic source, and to furnish the cold waters of Cape Ortegal it can only be ascribed to the melting ice of the mountains on the north coast of Spain. These flow along the coast from east to west until they meet the oceanic waters at Cape Finisterre.

During the months of November and December the temperature of the water is higher at Cape Ortegal than near the mouth of the Gironde. These are the months of the west winds on the coast of Portugal. These winds at the same time blow from the northwest on the French coast and suffice to explain the thermal difference.

These observations of the temperature of the sea clearly show that the waters of the Bay of Biscay are differently affected in summer and winter. During the fine season, in a period of comparative calms, in the Bay the surface waters are rather stationary, and are heated more than the coast waters by the influence of the winds and tides.

The experiments with drifting bottles show that in the summer months that the coast waters are subject to a slight movement. The Rennell Current has not the permanence nor the dimensions with which it is credited. In the Bay of Biscay there are variable coast currents depending upon the force and direction of the winds.

The conclusion that may be drawn from this study is that all the ocean currents marked on the charts are more or less deflected by the winds, and that even the most constant currents such as the Equatorial Currents, the Gulf Stream, and the Labrador Current are subject to their influence. The branch currents which wash the shores of western Europe and Africa are even more sensitive to the winds.

The currents on charts should be accepted as the general condition, but it must always be borne in mind that the wind dominates and is the grand factor in surface movements.

The changes in the temperature and saltness of the sea are also a principal cause of the movements of the waters, especially at certain depth. The effects of melting ice and fluvial discharges may be seen when the weather is calm, but numerous facts have shown that under these conditions the intermingling of the waters is slow without the agency of the wind.

It must also be admitted that there has been too much generalizing with conditions which in reality are only more or less frequent in certain seasons and not permanent. In making averages of observations one may get impressions which are not correct. Thus, in charts of mean barometer pressure and in isotherms in inter-tropical regions there is a fact which approaches the truth, since in these regions the extreme variations are only a few millimeters, but north of N. 40° what signification can be given to a barometer normal when it is known that in a few hours there may be changes of 75 mm., and that during an anticyclone the barometer remains at 785 for a week in a region where the normal is in fact 750 mm. The same in regard to the isotherms. The normal mean applies very well to inter-tropical regions and in the Atlantic east of the fortieth meridian, but in the neighborhood of the Banks of Newfoundland what will represent the conditions normally when the ice fields and icebergs appear and cover one-fourth of the Atlantic and then for another season fail to appear at all.

What more exact information can be obtained than is given on the Pilot Charts? There we see the tracks of depressions, the frequency of storms, the direction of currents, the direction of winds and percentage of calms which prevail in the Atlantic for the current month. If it were possible to add to the text of the Pilot Charts the disposition of the anticyclones and their interdependence in regard to the high pressure on the Sargasso Sea, one would see at a glance of the eye the actual state of affairs from the barometric indication.

*Temperature of the water in the Bay of Biscay from the mouth of the Gironde to Cape Finisterre (degrees Centigrade).*

| Longitude. | | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Seasonal differences. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° | ° |
| West of Paris | 4.. | 13.0 | 12.5 | 11.5 | 11.0 | 15.0 | 18.5 | 19.0 | 19.5 | 18.5 | 17.0 | 15.0 | 13.0 | 8.5 |
| Do. | 5.. | 13.0 | 12.5 | 11.5 | 11.0 | 11.5 | 18.0 | 19.0 | 19.5 | 19.0 | 17.5 | 16.0 | 14.0 | 8.5 |
| Do. | 6.. | 14.0 | 13.5 | 12.5 | 12.0 | 12.5 | 20.0 | 22.0 | 21.5 | 19.0 | 17.5 | 15.0 | 13.5 | 10.0 |
| Do. | 7.. | 14.0 | 12.0 | 11.0 | 11.5 | 12.5 | 16.5 | 19.0 | 20.5 | 19.5 | 18.0 | 16.0 | 14.0 | 9.5 |
| Do. | 8.. | 15.0 | 13.0 | 12.0 | 12.5 | 14.0 | 17.0 | 19.0 | 19.5 | 19.0 | 18.0 | 17.0 | 15.0 | 7.5 |
| Do. | 9.. | 14.5 | 12.0 | 11.0 | 12.0 | 14.0 | 17.0 | 19.0 | 19.5 | 18.5 | 17.5 | 16.5 | 14.0 | 8.5 |
| Cape Ortegal | 10.. | 14.5 | 13.0 | 12.0 | 12.0 | 13.5 | 17.0 | 18.0 | 19.0 | 18.5 | 18.0 | 17.5 | 15.5 | 7.5 |
| Do. | 11.. | 14.0 | 13.0 | 12.0 | 12.5 | 13.0 | 15.0 | 17.0 | 18.0 | 19.0 | 18.0 | 17.0 | 15.0 | 7.5 |
| C. Finisterre | 12.. | 13.0 | 12.0 | 12.0 | 13.0 | 14.0 | 17.0 | 19.0 | 19.5 | 18.0 | 17.0 | 16.0 | 14.0 | 7.5 |

It would also be valuable if a little subchart would show the tem-

peratures of the waters in the neighborhood of the Grand Banks as far as the northern limit of the Gulf Stream.

Finally, since this paper is addressed to the Meteorological Congress, they should formulate this resolution:

That the methods of giving information so accurately edited in the Pilot Chart should be adopted by all the maritime nations of Europe; that their methods of collecting information be adopted and the charts distributed with the same generosity; that the deposit of reports from log books be made obligatory, and that the captains be indemnified by frequent publications.

We think that by adopting this resolution the Congress will do a useful work, and in a great degree increase the security of life and property on the sea.

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## 9.—STORMS IN THE SOUTH ATLANTIC.

Capt. A. P. Pinheiro.

Honored with the confidence placed in me by the General Committee of the Congress of Meteorology to submit a report on the storms of the South Atlantic, I have sought to comply with this courteous invitation with the means which I had at my disposal, by touching upon the few data as yet known in the southern seas and taking a general view of the observations to the present time.

I, therefore, divide this work into two parts: (1) My own observations from 1874 to 1893, as to the present state of this information and as to what should be done for its progress and good practical result. (2) Historical observations as to the South Atlantic storms from 1789 to 1865, covering a period of about seventy-five years.[1]

(1) *Personal observations.*—Since 1874 I have always followed with interest the South Atlantic storms, and I observe that the storms follow a general direction from west to east and seek to throw themselves into the South Atlantic Ocean from the Pacific, or over the Brazilian territory.

I, therefore, bring before the Congress the fact that I am endeavoring once more, by utilizing the recent reorganization of the Meteorological Service of Brazil, brought about by Admiral Custodio de Mello, late Minister of the Navy, to realize my old scheme of connecting by telegraph the service of exchange of observations between Chile, Argentine Republic, and Uraguay, in order to follow with more precision the route of the storms in the South Atlantic, and later on I shall seek to connect the whole service of South America and to place it in daily correspondence with the United States of North America.

[1] The historical part of Capt. Pinheiro's paper comprises the interesting description of storms in the South Atlantic, read before the *Société Météorologique de France* in 1866, by M. Martin de Moussi, and printed in the *Annuaire* of the society, Vol. XIV. 1866. pp. 15-22; owing to limited space it is necessary to omit it here.—Editor.

When news reaches me by telegraph at Rio de Janeiro of the fall of the barometer at Valparaiso or Cordova, I know from past experience that after an interval of from three and a half to six days, according to the velocity of the wind, bad weather may be expected on the eastern coast of South America, as storms follow the general direction from west to east, spread themselves over the interior of Brazil, and become spent in the central states of Sao Paulo and Minas Geraes, or extend along the seacoast as far as the north of the State of Espirito Santo.

The winds of the South Atlantic, between S. 23° and S. 56°, proceed generally from west, southwest, and southeast; but north of about S. 13°, they blow more constantly from northeast to east, following the configuration of the coast to the mouth of the Amazonas. Unfortunately the observations made in the basin of the river are few. On the principal river east winds predominate during the greater part of the year, notably in the dry season from November until May, when they are rather strong. But in connection with the pamperos of the months of June and July, that is in the winter, they are still stronger.

Upon a superficial examination of the world we have in the northern hemisphere, as well as in the southern, movements of the air from the west toward the east. In storms these proceed with spiral circulations; in the former they are against the hands of the watch, and in the latter contrariwise. The tracks of storms then go eastward in both hemispheres.

The writer has established meteorological stations of the second order at Belem, the capital of the State of Grão Pará, and at Manáos, the capital of the State of Amazonas, in Brazil. After a series of observations shall have been made, it may be possible to connect the general atmospheric movements of both hemispheres. More stations will soon be in operation.

When I was at the International Conference in Munich two years ago, Mr. Wragge, of Brisbane, Australia, had already spoken to me about my giving him, by telegraph, information as to the southwest storms which pass over Brazil and which afterward cross over to those regions. In my opinion the meteorological service of the world, and more particularly the route of the storms, will have taken a great step to become better known, when, at a given hour, the directors of the various meteorological services of the world may be able to communicate with one another at a certain time (noon Greenwich) and study the various evolutions of capricious storms over the face of the terrestrial globe. A strict method in the observations, the mode of effecting the same, the development of the network of telegraphic stations, and a discussion in each of the countries where observations are taken in order that they may be subsequently sub-

mitted to and appreciated by the permanent committee of meteorlogists, all this will be a great advance toward determining the general laws of storms in the South Atlantic, and also for those of the whole world.

The small number of South American stations, the little reliance on the old instruments, and the manner of setting them up and observing them are sufficient reasons for declaring this knowledge still in a state of embryo in the South Atlantic, and, unfortunately, very little can as yet be said upon the subject even after consulting the few reports here referred to: C. F. Martins (Amazonas), 1831; Martin de Moussi (Montevideo), 1843–'52; Doazan (Buenos Ayres), 1866; Albert de Lisle (Montevideo), 1866; Manuel Eguia (Buenos Ayres), 1875; Morskoi Sbornik (Valparaiso), 1874.

Let, therefore, the above proposition go forth from the midst of this important conference, and for the realization of my scheme I call to my assistance the Congress Auxiliary of the World's Columbian Exposition.

END OF PART I.

Bulletin No. 11—Part II.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.

# REPORT

OF THE

# INTERNATIONAL METEOROLOGICAL CONGRESS,

HELD AT

CHICAGO, ILL., AUGUST 21-24, 1893,

UNDER THE AUSPICES OF THE

Congress Auxiliary of the World's Columbian Exposition.

## PART II.

EDITED BY
OLIVER L. FASSIG,
SECRETARY.

WASHINGTON, D. C.:
WEATHER BUREAU.
1895.

# PAPERS READ

BEFORE THE

# CHICAGO METEOROLOGICAL CONGRESS.

AUGUST 21-24, 1893.

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### 1.—THE CONNECTION OF THE ARMY MEDICAL DEPARTMENT WITH THE DEVELOPMENT OF METEOROLOGY IN THE UNITED STATES.

Maj. Charles Smart, U. S. A.

Meteorological science in the United States was conceived and brought forth by the Army Medical Department. It was nurtured carefully as well in the then unknown West as in the East, and it gained strength year by year. Its progress was occasionally announced from the office of the Surgeon General of the Army by such men as Forry, Espy, and Coolidge, and when it attained its maturity and was able to work its own way in the world, it was to one, once a member of the Army Medical Department, that it owed its establishment in its present prosperous line of business. The Weather Service of the United States may well be said to be the child of the Army Medical Department.

Gen. Joseph Lovell, the first Surgeon General of the Army, appointed in 1818, is usually credited with the honor of having instituted the Army Meteorological Service, although some of the credit is diverted to the then Secretary of War, the Hon. J. C. Calhoun, because he approved of the rules submitted by the Surgeon General, and so gave them the force of law. In urging the approval of the rule requiring a diary of the weather to be kept, Surg. Gen. Lovell remarked that "Every physician who makes a science of his profession or arrives at eminence in it will keep a journal of this nature, as the influence of weather and climate upon diseases, especially epidemic, is perfectly well known. From the circumstances of the soldier, their effects upon diseases of the Army are peculiarly interesting, as by proper management they may in a great measure be obviated. To this end every surgeon should be furnished with a good thermometer, and in addition to a diary of the weather, should note everything relative to the topography of his station, the climate, complaints prevalent in the vicinity, etc., that may tend to discover the causes of diseases, to the promotion of health, and the improvement of medical science."

Every reference to the subject published from the office of the Surgeon General gives credit to Dr. Lovell. In one of the volumes of meteorological tables it is stated, for instance, that "In 1819 a system of meteorological observations was commenced and zealously promoted by Surg. Gen. Joseph Lovell. The unpublished records extend to 1820." Even Surg. T. G. Mower, who, in 1843, read a paper at the centennial anniversary of the American Philosophical Society on the connection of the Army Medical Department with meteorological science, states positively that during the year 1818 the surgeons at military posts were directed to keep regular records of the weather and transmit them quarterly to the Medical Bureau at Washington and that the earliest registers thus transmitted and on file in the Surgeon General's Office are dated January, 1819.

Nevertheless it appears that Surg. Gen. Lovell's credit must be restricted to the fact that he appreciated the value of the existing rules of the Medical Department, in regard to meteorological observations, and continued them instead of dropping them out, as he might have done. The earliest meteorological journal on file in the office of the Surgeon General, instead of bearing date January, 1819, is dated at Cambridge, Mass., July, 1816. On its first page is written the following:

> Among the rules for the medical staff of the Army of the United States is that which makes it the duty of each hospital surgeon and director of a department "to keep a diary of the weather, together with an account of the medical topography of the country in which he serves." Wherefore the following sketch of Boston and its vicinity, and particularly of Charlestown, is offered to the commander in chief, Maj. Gen. Brown, by Benjamin Waterhouse, M. D., hospital surgeon and director of Department No. 2, Northern Division, as a first step in fulfilling this desideratum.
>
> CAMBRIDGE, July, 1816.

From this introductory sentence the inference is warranted that this meteorological report was a new thing to Dr. Waterhouse, and that no doubt it was the first of the kind that he had submitted. In going back through the Military Laws, Rules, and Regulations of the United States, an order may be found, dated May 2, 1814, which makes it a duty of hospital surgeons to keep a diary of the weather. Prior to this date neither the regulations of the Army nor the rules of the Medical Department made any reference to such a duty. Dr. James Tilton, of Delaware, was then the Physician and Surgeon General of the Army. He had been appointed in 1812 on account of his record as a hospital surgeon during the Revolutionary war and of his published views on hospital organization, which had been presented to Congress at the close of that war. As the order directing the keeping of a diary of the weather was issued during his administration, the credit of originating it belongs officially to him. He was occupied at the time on the northern frontier looking after the interests of the sick and wounded. The battles of Chippewa, Bridgewater, and Platts-

burg took place during this summer, and one would have supposed that Army medical officers would have had more urgent matters to attend to than the observation of the weather; but when it is considered that Tilton had devoted much of his life to the organization and administration of hospitals, and that only hospital surgeons and those elevated to the position of medical directors were called upon to make the observations, there seems to be little doubt that the credit of instituting meteorological records at our permanent posts and hospitals should belong actually as well as officially to this officer.

The meteorological journal, to which the topographical remarks of Dr. Waterhouse form an introduction, gives three observations daily, 7 a. m., and 2 and 9 p. m., on the barometer, thermometer, face of sky, and winds, with a column for remarks. The condition of the sky is indicated by hieroglyphics, such as ⊙ fair, $\div$ mostly fair, $-\!\!\equiv$ few clouds, $\dot{\equiv}$ mostly cloudy, $=\,=$ cloudy, ‡‡ rain, ‡ snow, and the force of the wind by a numerical exponent to the letters indicating direction, thus $SW_2$.

The regulations of the Medical Department issued in 1818, immediately after the appointment of Dr. Lovell as Surgeon General of the Army, spoke thus of the duties of a hospital surgeon: "He shall keep a diary of the weather in the form and manner prescribed, noting everything of importance relating to the medical topography of his station, the climate, complaints prevalent in the vicinity," etc. Of an assistant surgeon: "He shall make the proper entries in the book containing the diary of the weather." Of a regimental surgeon: "He shall observe all the regulations given for the surgeon attending a general hospital in relation to * * * the book containing a diary of the weather, the medical topography of his post or station, etc.; and if both the regimental mates be present the senior shall see that the diary of the weather be properly kept." Of a post surgeon: "He shall observe all the regulations given for a surgeon attending a general hospital in respect to the books to be kept."

It seems, therefore, that although Dr. Tilton instituted the records, the circumstances attending the war with Great Britain prevented an efficient compliance with the requirements of his order of May 2, 1814, and it was left to Dr. Lovell, favored by a prolonged period of peace and prosperity, to take up the suggestion and develop its usefulness.

In 1826 the first results of the work of the Army Medical Department in this direction were given to the world in a volume entitled "Meteorological Register for the years 1822–'25, inclusive, from observations made by the surgeons of the Army at the military posts of the United States; prepared under the direction of Joseph Lovell, M. D., Surgeon General of the U. S. Army, Washington, 1826." The

meteorological tables in this volume were intended as a contribution and stimulus to the solution of the question whether, in a series of years, there is any material change in the climate of a country and, if so, how far it depends upon the cultivation of the soil, density of population, etc.; for at the time of publication contradictory opinions were held, some contending that as population increased and civilization extended the climate became warmer, others that it became colder, and others again that there was no change. The military posts from which observations were given numbered 18, including Washington, and were situated between N. 27° 57′ and N. 46° 39′ and W. 67° 04′ and W. 95° 43′. Fort Snelling, near the junction of the St. Peters and the Mississippi rivers, was the extreme northern and Cantonment Clinch, near Pensacola, the extreme southern station. The posts having the highest elevation were Council Bluffs, believed to be about 800 feet, and Fort Snelling, about 780 feet above the sea level. The observations from all the posts were arranged in monthly tables with a consolidation for each year and a similar consolidation for the whole period. The latitude and longitude of each place of observation were given, the mean temperature at 7 a. m., 2 and 9 p. m., the aggregate of mean temperature, the highest and lowest degrees and the range, the wind expressed in days of prevalence from each of 8 different points of the compass, and the weather in days of fairness, cloudiness, rain or snow. It was the intention, if similar observations could be obtained for eight or ten years, to collect such as had been made at an early period of the settlement of the country and to ascertain what changes had taken place in the Atlantic States, either in the mean temperature, the range of the thermometer, the winds, or the weather.

The next publication was much more elaborate and embodied the data of the first volume by way of an appendix, in order to present the whole of the observations at one view. "Meteorological Register for the years 1826–'30, from observations made by the surgeons of the Army and others at the military posts of the United States, prepared under the direction of Thomas Lawson, M. D., Surgeon General, U. S. Army. Philadelphia, 1840. To which is appended the Meteorological Register for the years 1822–'25, compiled, etc. (published for the use of the Medical Officers of the Army)." The tables in the record for 1826–'30 were similar to those in the previous publication to permit of comparison and consolidation. The compilation and able discussion of the results presented in this volume were the work of Assistant Surg. Samuel Forry, U. S. Army. For the better presentation of the observed facts the country was divided into a northern, middle, and southern division. In the first, on the sea coast of New England, the influence of the ocean was found to modify the range of the thermometer and the mean temperature of the seasons. In the

interior of New York the range increased and the seasons were violently contrasted. Further west near the Great Lakes a climate similar to that of the seaboard was again found; and in the interior beyond them extreme ranges became the rule. For example, the mean temperature of Atlantic and interior posts in the same latitude was found to be the same, but in the East that of winter was 6.05° higher, of spring 4.13° lower, of summer 8.71° lower, and of autumn 0.40° higher than in the West; and the influence of altitude was excluded from the observations which gave these results. The influence of the ocean was expressed also by the fact that the number of wet or foggy days on the New England coast was one-half greater than in the interior.

Similar contrasts in the seasons and weather were discovered also in comparing the Lake posts with those beyond. The posts selected were Forts Brady, Mackinac, and Snelling, from 575 to 780 feet above the sea level. In the middle division similar laws were found to prevail. The seasons grew less uniform as the West was penetrated. Washington City and Fortress Monroe showed less difference between the mean temperature of summer and winter than Jefferson Barracks or Fort Gibson. In the southern division, bounded by the Gulf of Mexico, the seasons glided imperceptibly into each other, showing no great extremes. Thus, the difference between the mean temperature of the warmest and coldest month at Cantonment Brooke, in Florida, was only 17.68°, while that at Fort Snelling was 61.18°. It was developed further that the extremes of heat and cold did not occur at our most southern and northern posts, as these were situated on large bodies of water which exercised a modifying influence. Brady had a more equable climate than Snelling, and the mean summer temperature of Augusta, Ga., was greater than at the Florida posts. Lastly, it was discovered that the summer of a southern post differs from that of a northern one rather in its duration than in its intensity. In fact, the isotheral, isocheimal, and isothermal lines as far west as Fort Snelling became pretty well defined by a study of the observations thus far recorded. The prominent features of the climate of the country having been thus outlined, it was expected that a continuance of the observations would in course of time permit of the composition of a complete meteorological chart. To this end the Surgeon General procured from Europe a number of Daniell's hygrometers for use at the more important stations, and De Witt's conical rain gauge was furnished to those posts not already provided with this instrument.

About the same time was published a "Statistical report on the sickness and mortality in the Army of the United States, compiled from the records of the Surgeon General's and Adjutant General's Offices, embracing a period of twenty years, from January, 1819, to

January, 1839, prepared under the direction of Thomas Lawson, M. D., Surgeon General, Washington, 1840." This work defined the sanitary conditions of each of the posts, detailed the more important incidents of their medical history, and concluded with a discussion on the relationship of climate and its seasonal differences to mortality, and the prevalence of such diseases as fevers, diarrhœas, catarrhs, and pulmonary diseases, rheumatism, etc. Two years later Forry republished the matter of his meteorological and statistical reports as a work on "The climate of the United States and its endemic influences." New York, 1842. 8°.

When Dr. Forry resigned in 1840 Mr. J. P. Espy became attached to the Surgeon General's Office to collate the meteorological journals and study the steadily accumulating mass of facts. This gentleman, an enthusiast in meteorological science, was already well known by his book "On the Philosophy of Storms." He immediately sent out a circular letter urging the keeping of meteorological journals by voluntary observers throughout the country, by colleges, high schools, naval and lighthouse stations, etc., on the forms prescribed for the Medical Department of the Army, especially requesting co-operation in his efforts to develop the phases of storms. By charting on skeleton maps the observations taken as a storm was passing he expected to determine its shape and size, whether round or oblong, and if the latter, whether it moved side foremost, end foremost, or obliquely, its velocity and direction, together with the direction of the wind at and beyond its borders, the barometric and thermometric changes accompanying it, and the extent to which such changes were felt. In 1843 he received journals from 50 observers who noted barometer changes and from 60 others who had no barometer, and in the preparation of his First Report to the Surgeon General of the Army he utilized the observations of the months of January, February, and March of that year. Twenty-nine beautifully engraved charts accompanied his report and illustrated the weather of the three months. On these charts the direction and length of the arrows showed the direction and force of the wind, the points being near the places of observation. The rain or snow fall was indicated by figures in red. A long black line represented the various maxima of pressure as shown by the barometer and a long red line the various minima. In brief, his deductions were that storms travel from west to east and have a central line of minimum pressure often of great length and at right angles to the direction of its advance. The storm in fact crosses the country like a line of battle, sometimes nearly straight, but generally with a convexity eastward at some point as if an impulse was carrying it forward there at a greater rate than the average of 36 miles an hour. The wind sweeps inward from all directions toward the storm center, its

force and the extent of the disturbance around the line of diminished pressure being proportioned to the suddenness and magnitude of the barometric fall; when the latter is great the disturbance may extend for hundreds of miles, and is always accompanied by rain or snow. Fluctuations are greater at the north than at the south. During the passage of a storm the wind passes from easterly to westerly by way of the north in the northern parts of the country, by way of the south in the southern parts. Storms usually begin in the far west beyond the sphere of the observations then made. Meanwhile the area of maximum pressure, also linear and disposed longitudinally, retires eastwardly before the advance of the storm and disappears over the Atlantic Ocean as the storm line reaches the western border of New England, after which the line of maximum pressure reappears in the southwest, following up the storm that is now withdrawing beyond the Atlantic coast line. There is little wind near the line of greatest pressure, and in direction it is generally away from the line.

Mr. Espy concluded his report by a suggestion which has since then been happily carried into effect:

It is highly desirable to surround storms and keep them constantly in view from their beginning to their end. Now, as the barometer generally sinks more during the passage of our great winter storms in the northern part of the United States than in the southern, is it not probable that the northern half of many of these storms is entirely beyond the bounds of our observations? And, as these storms certainly reach Newfoundland in their progress toward the east, is it not probable that they do not break up before they advance far into the ocean? May not some of them even reach the shores of Europe? Under these circumstances would not the governments of England and France, if they were requested by the proper authorities, order the masters of the numerous steamers which now ply the Atlantic to send copies of their journals to Washington City to be collated with those received now from so many other quarters?

What high utilities to the mariner, and through the mariner to all mankind, might not reasonably be anticipated from such a system of wide-spread, simultaneous observations, continued long enough to compare with each other, not merely the storms of different seasons but the storms of different years.

The merest glance at Espy's charts demonstrates the fact that telegraphic communication was the only thing wanting to enable that enthusiast to plan the very weather service that we have at the present day. Meanwhile, owing to the impetus which he had given to meteorology, a board of officers, consisting of Drs. Mower, Steinecke, and Cuyler, formulated "Directions for taking Meteorological Observations adopted by the Medical Department of the Army," which were published in 1844. Observations were required daily at a little before sunrise, at 9 a. m., and 3 and 9 p. m. on the barometer and its attached thermometer, the detached thermometer, the wind, and the weather; the wet bulb was noted twice only, before sunrise and at 3 p. m. Bunten's siphon barometer, the wet bulb, and a conical rain guage were issued. Tables were given for the conversion of the French barometric scale into English inches, and for the translation

of centigrade degrees into those of Fahrenheit's scale. Clearness of sky was directed to be indicated by the numerals 0–10, the first representing no clearness, the last no cloud; the force of wind was to be reported in like manner, 0 signifying a calm and 10 a violent hurricane. Hourly observations were called for on the 21st days of March, June, September, and December, beginning at 6 a. m. and ending at the same hour next day.

Evidently the Medical Department at this time intended to give renewed energy to the development of meteorological science, for Dr. Mower's paper, already cited and which may be regarded as official, closes with a cordial invitation to colleges, scientific institutions, and individual students of meteorology to co-operate with the department, placing its forms at their disposition and stating that all contributions will be cheerfully acknowledged in the publications of the department. Arrangements, he says, have been made for prosecuting meteorological inquiries with renewed diligence; and a medical officer will shortly be detailed to give his chief time and attention to the subject, to arrange and digest the matter collected, and to prepare the results for publication.

It was not, however, until 1851 that the next publication from the office of the Surgeon General was issued. "Meteorological Register for twelve years, from 1831 to 1842, inclusive, compiled from observations made by the officers of the Medical Department of the Army at the military posts of the United States, prepared under the direction of Bvt. Brig. Gen. Thomas Lawson, Surgeon General, U. S. Army, Washington, 1851." And notwithstanding the delay in publication no effort was made to collate the observations and deduce general results from the mass of facts presented. The tables embraced the records of 62 posts lying between N. 24° 20′, Key West Barracks, and N. 47° 15′, Fort Kent, Me., and between W. 66° 58′, Fort Sullivan, at Eastport, Me., and W. 95° 10′, Fort Gibson, Cherokee Nation, Ark.

Five years later appeared a "Statistical Report on the Sickness and Mortality of the Army of the United States, compiled from the Reports of the Surgeon General's Office, embracing a period of sixteen years from January, 1839, to January, 1855, prepared, etc., by R. H. Coolidge, Assistant Surgeon, U. S. Army, Washington, 1856." This volume contained a series of tables, one for each of 159 posts, giving the mean results of the observations of temperature for each month, season, and year during the entire period of the observations at each. The rainfall, wind, and weather were given in another series of tables.

A similar statistical report was issued in 1860, covering the period of five years, January, 1855, to January, 1860, also by Dr. Coolidge.

This brings us to the war of the rebellion, with the meteorological records of forty years before the public. The original reports had often been consulted by officers engaged in explorations for a railroad

from the Mississippi to the Pacific and on various boundary surveys, and by those desirous of elucidating some special point in meteorology. From January, 1819, to January, 1841, the observations were made three times daily, at 7 a. m., 2 and 9 p. m.; in 1841 at sunrise, 2 and 9 p. m.; in 1842 at sunrise, 2 p. m., sunset, and 9 p. m.; in 1843–'55 at a little before sunrise, 9 a. m., and 2 and 9 p. m.; but as an extended examination of the records of the hourly observations showed that the mean of the observations taken at 7 a. m., and 2 and 9 p. m. more nearly approximated the true daily mean than did the means of any of the four daily observations, orders were issued directing a return to the three daily observations at those hours.

In following up the connection of the Medical Department of the Army with the progress of meteorological science, it is proper at this stage to refer to the history of one member of the Department, Assistant Surg. A. J. Myer. This officer was appointed in 1854 and served until 1860, when he vacated his position to accept that of Signal Officer of the Army. During his frontier service he drafted a code of signals which, in 1858, was approved by a board of critical officers. With his efforts to build up a valuable signal service and the difficulties he encountered this paper has no concern, nor with his ultimate success in obtaining legislation for a signal corps organization at a time when, through the antagonism of the Secretary of War, he was relieved from its command. During the war of the rebellion the discovery and transmission of information regarding the movements of the enemy's forces and the well-being of our own absorbed all the energies of the newly-formed corps, but at its close in 1866, when the military establishment was reduced to a peace footing, Gen. Myer, who had happily been recalled to the head of the Signal Corps, looked naturally for some service or duty for his command in line with its military duties that would enable it to be of value to the country during the coming years of peace. Nonmilitary work by military men was no innovation in this country, for the Engineer Department of the Army had in times of peace surveyed the Western Territories, built bridges and levees, deepened rivers and harbors, and constructed many important works of internal improvement. Gen. Myer's six years of service as a post surgeon, during which he became familiar with the meteorological work of the Medical Department and the progress of storms across the continent as developed by Mr. Espy, led him to urge upon Congress the advantageous possibilities suggested by the observation of storms and the prompt signalling of their approach. Not until February, 1870, however, was he authorized to undertake this work, when he immediately established 66 stations, equipping each observer as he himself had formerly been equipped by the Medical Department, but furnishing in addition an anemometer to obtain a more precise knowledge of the force of coming

storms. Each observer transmitted his observations by telegraph to the central station at Headquarters of the Signal Corps, Washington, D. C., where all were plotted on a skeleton map and studied to determine the atmospheric conditions and the movements and forces of storms in precisely the same way that Mr. Espy dealt with the data which he received by mail long after the occurrence of the events. Mr. Espy knew how the storm had traveled; Gen. Myer knew how the storm was traveling. This constituted the difference between the old and the new. The former published his knowledge of the completed event as a contribution to science and the possibilities of the future; the latter conveyed his knowledge of the coming event by telegraph and signals to all who were concerned in the progress of the passing storm. Subsequently, Gen. Myer established an International Weather Bulletin and Weather Map based on simultaneous observations, thus carrying into present practice the suggestion contained in that paragraph of Mr. Espy's report that has just been cited.

Since 1874 all meteorological reports from Army Medical Officers have been turned over to the Chief Signal Officer or to his successor in charge of the Weather Bureau. It might be supposed that since the value of this Bureau has been so thoroughly established its important position would render it wholly independent of the officers whose labors in the past had done so much to establish it; but this is not so. Meteorological observations have been discontinued at those military posts near which the Weather Bureau has installed its observers, but there are yet many parts of our vast country occupied by military posts where no station of the Weather Service has been established. At these military posts, some 50 in number, medical officers continue to make their meteorological observations as their predecessors did in the early days after the issuance of the order of May 2, 1814, which made it the duty of hospital surgeons to keep a diary of the weather.

Long and faithfully have the medical officers of the Army obeyed that order, and with honorable pride they can point to the results that have been achieved.

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## 2.—THE METEOROLOGICAL WORK OF THE SMITHSONIAN INSTITUTION.

S. P. Langley, Secretary.

The Smithsonian Institution has always made it a rule of action to undertake such lines of work as point the way to great public utilities, and these have subsequently been made the function of useful government bureaus of applied science.

This is notably true in the case of meteorology, which was developed by the Institution, in both its scientific and its popular

aspects, until its importance became so well understood, and its utility so widely appreciated, that, in 1870, Congress made it the duty of the Chief Signal Officer of the United States Army to observe and report storms for the benefit of commerce and agriculture.

The interest of the Smithsonian Institution in meteorology began with the organization of its work by its first secretary, Prof. Joseph Henry, in 1847, and from that time to the present—nearly half a century—meteorological science has been granted an important share of its labors and expenditure.

In his "Programme of Organization," submitted on the 8th of December, 1847, in giving examples of objects for which appropriations might properly be made, the Secretary mentioned first, and urged upon the immediate attention of the Institution, a "System of extended meteorological observations for solving the problem of American storms." This clear appreciation of the existing state of knowledge, and of the utilities to be gained, are set forth in the following words, with which he commends this undertaking:

> Of late years, in our country, more additions have been made to meteorology than to any other branch of physical science. Several important generalizations have been arrived at, and definite theories proposed, which now enable us to direct our attention, with scientific precision, to such points of observation as can not fail to reward us with new and interesting results. It is proposed to organize a system of observation which shall extend as far as possible over the North American continent. The present time appears to be peculiarly auspicious for commencing an enterprise of the proposed kind. The citizens of the United States are now scattered over every part of the southern and western portions of North America, and the extended lines of the telegraph will furnish a ready means of warning the more northern and eastern observers to be on the watch for the first appearance of an advancing storm.

In the inauguration of this system of observation, Prof. Henry solicited the suggestions of the most experienced American meteorologists—Espy, Loomis, and Guyot—who extended their cordial co-operation.

Accompanying the above-quoted presentation of his programme, the Secretary published a valuable, and now historic report, by Prof. Loomis, upon the meteorology of the United States, in which he showed what advantage society might expect from the study of storms, what had already been done in this country toward making the necessary observations, and, finally, what encouragement there was to a further prosecution of the same researches. He then presented, in detail, a plan for unifying all the work done by existing observers, and for supplementing it by that of new observers at needed points, for a systematic supervision, and, finally, for a thorough discussion of the observations collected.

On December 13, 1847, the Board of Regents adopted the Programme of Organization, and on the 15th inaugurated the system of meteorological observations by an appropriation of $1,000 for the purchase of instruments and other related expenses.

In the following year (1848), Prof. Espy, who was then the official meteorologist of the Navy Department, was assigned to duty under the direction of the Secretary of the Smithsonian Institution. In connection with Espy, the Secretary (Henry) addressed a circular letter to all persons who would probably be disposed to take part in the contemplated systems of observations, and co-operation was solicited from the existing systems under the direction of the Surgeon General, and of the States of New York and Pennsylvania. As a result of these efforts, the Institution, at the close of 1849, already had 150 daily observers, and the number continued to increase.

In order to unify the methods adopted by observers, Prof. Guyot was requested to prepare a pamphlet of "Directions for Meteorological Observations,"[1] which was published in 1850, and to compile a collection of meteorological tables, which was published as a volume of the "Miscellaneous Collections" in 1852. In 1857, after careful revision by the author, a second and much enlarged edition of the tables was published, and in 1859, a third, with further amendments. Although designed primarily for the meteorological observers reporting to the Smithsonian Institution, the tables obtained a much wider circulation, and were extensively used by meteorologists and physicists in Europe and the United States. An important step taken at the inception of the Smithsonian system was the introduction of accurate instruments. Standard barometers and thermometers were imported from Paris and London, with which those made for the use of the Institution were compared, and sets of such apparatus were furnished to observers.

In 1849, Prof. Henry personally requested the telegraph companies to direct their operators to replace in their regular morning dispatches the signal "O K," by which they were accustomed to announce that their lines were in order, by such words as "fair," "cloudy," etc., thus giving, without additional trouble, and as concisely as possible, a summary of the condition of the weather at the different stations, and which should be communicated to him. This request was complied with, and such elementary telegraphic weather reports were thus furnished the Institution daily without charge. This action of Prof. Henry, which has sometimes been erroneously ascribed to Prof. Espy, was the beginning of telegraphic weather service, nothing of the kind having been attempted in Europe until a later date, and by means of these reports predictions of coming storms, with all the now recognized advantage to the country at large, were made possible. With the material thus obtained the Institution was enabled in 1850 to

[1] Smithsonian Institution. "Directions for Meteorological Observations," intended for the first class of observers. Washington City, 1850. Reprinted with additions in Annual Report for 1855, and again as a part of the Smithsonian "Miscellaneous Collections" in 1870.

construct the first *current* weather map, giving daily, from "live data," the meteorological conditions over the whole country. This map was hung where the public could have general access to it to observe the changes; and its indications were first published at large by signals displayed from the high tower of the Institution. This method was followed and further extended by publications in the Washington "Evening Star," in 1857, and such general interest was manifested in the subject that telegraphic weather reports were thereafter furnished to the "Star" for daily publication. This systematic notification of the general public by the press and otherwise of weather observations appears then to have been undoubtedly due to Henry, and unquestionably to have preceded by a year a similar publication in 1858 of Leverrier, to whom this pioneer step has been erroneously attributed.

In 1858, the meteorological map already in use was improved by the adoption of circular disks of different colors, which were attached to it by pins at each station of observation, and indicated by their color the state of the atmosphere—white signifying clear weather; gray, cloudy; black, rain, etc. The disks had an arrow stamped upon them, and, as they were so arranged that they could be attached to the map in any direction, the motion of the wind at each station was shown by them, and the "probabilities" thus more accurately forecast.

The study of the meteorological data, begun in 1849, continued under the direction of the Institution for twenty-five years, during which time numerous publications were issued relative to temperature, rainfall, hygrometry, and casual phenomena, while popular information was continuously disseminated by publishing telegraphic weather reports, maps, etc. Among the associates of the Institution in this branch of investigation may be mentioned Prof. Espy, and later, Prof. J. H. Coffin, Mr. C. A. Schott, and others. Their work may be concisely described as follows: Prof. Espy utilized the already collected data in the preparation of his Third and Fourth Meteorological Reports. After the Smithsonian observations were practically completed Mr. Schott[1] took the data and prepared elaborate tables of temperature and precipitation, which were published in the Smithsonian "Contributions to Knowledge."

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[1] Schott, C. A. Base-chart of the United States. Discussion of Caswell's meteorological observations at Providence, R. I.; Cleaveland's meteorological observations at Brunswick, Me.; Hayes' physical observations in the Arctic Seas; Hildreth and Wood's meteorological observations at Marietta, Ohio; Kane's astronomical observations in the Arctic Seas; Kane's magnetic observations in the Arctic Seas; Kane's meteorological observations in the Arctic Seas; Kane's physical observations in the Arctic Seas; Kane's tidal observations in the Arctic Seas; McClintock's meteorological observations in the Arctic Seas; Smith's meteorological observations made near Washington, Ark.; tables, distribution, and variation of atmospheric temperature; tables of rain and snow in the United States.

Prof. Coffin[1] compiled his great work on the laws of the winds, and contributed various lesser works to the bibliography of the Institution on meteorological subjects.

The first collection of meteorological tables, compiled by Dr. Guyot at the request of the Institution, was published in 1852, as a volume of the Smithsonian "Miscellaneous Collections," and new editions were published in 1857 and 1859. Twenty-five years later the work was again revised and a fourth edition was published (1884). The demand for these tables exhausted this edition in a few years; it was then decided to recast the work entirely and publish still another in three parts—one of meteorological, one of geographical, and one of physical tables, each representative of the latest knowledge in its field, and independent of the others, but the three forming a homogeneous series.

The desirability of establishing a meteorological department under one comprehensive system, with an adequate appropriation of funds, was frequently urged by the Smithsonian Institution, and in 1869 an appropriation of $25,000 was made by Congress for the adoption and maintenance of a code of weather signals on the Northern Lakes, under the direction of the Chief of the Signal Corps of the United States Army. The Government having thus evinced a willingness to take charge of the meteorological system of the country, and it being the policy of the Institution to do nothing which could be accomplished as well by other means, the work of the Smithsonian in this direction was freely relinquished by the Institution, although its formal transfer to the War Department did not take place until 1874.

During the period when the Smithsonian was directly in charge of meteorological researches in the United States its expenditures in this connection, which had been voluntarily assumed, were over $60,000. In addition to this, the Institution made a contribution of incalculable value in the stimulus given to investigations of this class by the active, personal interest of its first secretary, who always devoted much time and thought to this subject, while, even after the transfer of the Smithsonian system to the War Department, the discussion and publication of the material already accumulated was continued by it. The Smithsonian Institution may then be termed the parent of the present Weather Bureau.

In 1891, the present Secretary (Mr. S. P. Langley) deposited in the U. S. Signal Office all the voluminous monthly records of the Institution, and all the manuscript and printed observations and contributions relating to meteorology, subject to recall, but with the understanding that the entire official record of research and progress in this connection should be preserved intact by the Bureau which now has these investigations in charge.

[1] Coffin, J. H. Orbit and phenomena of meteoric fire ball. Psychrometrical tables. Storms of 1859. Winds of the globe. Winds of the Northern Hemisphere.

## 3.—THE ORIGIN AND WORK OF THE DIVISION OF MARINE METEOROLOGY.

Lieut. W. H. Beehler, U. S. Navy.

The Division of Marine Meteorology in the Hydrographic Office of the U. S. Navy Department may be strictly said to have had its origin when Lieut. Maury became the Superintendent of the U. S. Naval Depot and Observatory in September, 1844.

Lieut. Maury's energies were almost entirely devoted to the hydrographic and meteorologic subjects, and he took immediate steps to collect information from the log books of men-of-war and merchant vessels for the preparation of charts to show the prevailing winds and currents, their limits and general characteristics, the best sailing routes, the limits of fog, field ice, icebergs, and rain areas, all the physical features of the ocean, the feeding ground of whales, and all facts of interest or value to mariners.

These charts are known as Maury's "Wind and Current Charts." They include Track Charts, Trade-wind Charts, Pilot Charts, Whale Charts, Thermal Charts, and Storm and Rain Charts.

As soon as merchant mariners understood the object and nature of this work they readily forwarded their log books for examination, and have ever since promptly furnished all information in their power. Indeed, the voluntary co-operation of the mariners of all nationalities in developing the science of marine meteorology deserves the highest praise and our most profound gratitude.

Lieut. Maury was Superintendent for seventeen years, 1844 to 1861, during which he published the seven series of Wind and Current Charts, together with eight volumes of Sailing Directions, containing elaborate articles on ocean meteorology and nautical information.

The Track Charts, or "A" series, comprise the North Atlantic Track Charts in eight sheets; the South Atlantic Track Charts in six sheets; the North Pacific Track Charts in eleven sheets; the South Pacific Track Charts in ten sheets; and the Indian Ocean Track Charts in eleven sheets. They show the frequented parts of the ocean, the general character of the weather and wind, and the force and direction at the different seasons of the year. They were compiled by Lieuts. Whiting, Humphreys, Porter, Wyman, Balch, Gibbon, Beaumont, Aulick, Welch, Temple, Wells, Fillebrown, Badger, and Woolsey, and Profs. Flye and Benedict, of the U. S. Navy.

The Trade-wind Charts, or "B" series, by Lieut. De Haven, consist of one sheet of the Atlantic; besides which there is one sheet, a Trade Wind and Monsoon Chart of the Indian Ocean, by Lieuts. Guthrie, Newcomb, Van Zandt, Stout, and Houston. These show the limits, extent, and general characteristics of the trade-wind regions, together with their neighboring zones of calms.

The Pilot Charts, or "C" series, comprise the North Atlantic in two sheets; the South Atlantic in two sheets; the Brazil in one sheet; the Cape Horn in two sheets; the North Pacific and South Pacific Pilot Charts. The Pilot Charts of the Indian Ocean are included in those of the Pacific.

The officers employed on these charts were Lieuts. Ball, Herndon, Dulany, Harrison, Forest, Wainwright, Guthrie, DeKoven, Deas, and Fitzgerald, and Passed Midshipmen Davenport, Powell, Balch, Roberts, DeKrafft, Woolsey, Jackson, Murdaugh, Semmes, Wells, Lewis, Brooke, Johnson, Terret, and Prof. Benedict. These charts show in every square of five degrees the direction of the wind for 16 points of the compass that will be probably found in that square during each month of the year, based upon the number of times the wind was reported to have been from that direction in former years; a time was a period of eight hours.

The Thermal Charts, or "D" series, include the North Atlantic Thermal Chart in eight sheets; the South Atlantic Thermal Chart in six sheets; the North Pacific Thermal Chart in eleven sheets; the Indian Thermal Chart in eleven sheets (not completed).

These charts were the work of Lieuts. Gant, Gardner, and Prof. Flye. These show the temperature of the surface of the ocean wherever and whenever it had been observed. The temperatures are distinguished by colors and symbols, in such a manner that mere inspection of the chart shows the temperature for any month. The four seasons of the year are distinguished by the symbols. Isothermal lines for every 10° of surface temperature are also drawn on these charts.

The Storm and Rain Charts, or the "E" series, comprise those of the North and South Atlantic, each in one sheet. They were compiled by Lieuts. W. R. Taylor, Ball, Minor, Beaumont, Guthrie, and Young. They show in every square of five degrees the number of observations had for each month, the number of days in which there was rain, a calm, fog, lightning and thunder, or a storm, and the quarter from which it blew.

The Whale Charts, or the "F" series, are in four sheets for the whole world. They show where whales are most hunted, in what years and months they have been most frequently found, whether in shoals or stragglers and whether sperm or right. These charts were compiled by Lieuts. Herndon and Fleming and Passed Midshipmen Welch and Jackson.

The physical map of the ocean was not completed.

Some idea of the work accomplished can be formed from the fact that 200,000 copies of the Wind and Current Charts, and 20,000 copies of the "Sailing Directions" were issued gratuitously to the masters of merchant vessels who had furnished information.

One of the most important historical events connected with Maury's meteorological work was the meeting of the first International Meteorological Congress.

The Maritime Conference held at Brussels for devising a uniform system of meteorological observations at sea met at the residence of the Belgian Minister of the Interior on the 23d of August, 1853, and adjourned on the 8th of September, 1853.

The governments participating were represented by the following officers, viz:

Belgium, by A. Quetelet, Directeur de l'Observatoire Royale, and Victor Lahure, Capitaine de Vaisseau, Directeur Général de la Marine.

Denmark, by P. Rothe, Capt.-Lieut., Royal Navy, Director Depot Marine Charts.

France, by A. Delamarche, Ingénieur Hydrographe de la Marine Impériale.

Great Britian, by F. W. Beechy, Captain, Royal Navy, F. R. S., and Henry James, Captain, Royal Engineers, F. R. S.

Netherlands, by M. H. Jansen, Lieutenant, Royal Navy.

Norway, by Nils Ihlen, Lieutenant, Royal Navy.

Portugal, by J. de Mattos Correa, Capt.-Lieut., Royal Navy.

Russia, by Alexis Gorkovenko, Capt.-Lieut., Imperial Navy.

Sweden, by Carl Anton Pettersen, First Lieutenant, Royal Navy.

United States, by M. F. Maury, LL. D., U. S. Navy.

At the first session of the Conference, Mr. Quetelet was made President, and Lieut. Maury was called upon to explain the object of his mission, which he did in the following words, viz:

GENTLEMEN: The proposal which induced the American Government to invite the present meeting originated with the English Government, and arose from the communication of a project prepared by Capt. Henry James, Royal Engineers, by order of Gen. Sir John Burgoyne, in which the United States Government was invited to co-operate.

Nineteen stations had been formed by the English authorities upon a uniform system, and the direction of the observations confided to the immediate supervision of the officers in command of the respective stations. In the United States meteorological observations had been made since the year 1816.

The American Government sympathized with the proposal of the English Government, but said include the sea, and make the plan universal, and we will go for it. I was then directed to place myself in communication with shipowners and commanders of the Navy and mercantile marine, in furtherance of the plan.

With a view, however, of extending still farther these nautical observations, the Government of the United States decided upon bringing the subject under the consideration of every maritime nation, with the hope of inducing all to adopt a uniform log book.

In order to place the captains navigating under a foreign flag in a position to co-operate in this undertaking, Mr. Dobbin, Secretary of the Marine Department at Washington, has instructed me to make known that the mercantile marine of all friendly powers may, with respect to the Charts of the Wind and Currents, be placed on the same footing as those of the American Marine; that is to say, that every captain, with-

out distinction of flag, who will engage to keep his log during the voyage upon a plan laid down, and afterwards communicate the same to the American Government, shall receive, gratis, the Sailing Directions and Charts.

It has, consequently, been suggested to the captains that they should provide themselves with, *at least*, one good chronometer, one good sextant, two good compasses, one marine barometer, and three thermometers for air and water. I make use of the expression, *at least*, because the above is the smallest number of instruments with which a captain can fulfill the engagements he contracts upon receiving the charts. Foreign flags will thus enjoy the advantage of profiting at once by all the information collected up to this time. You will not fail to observe, gentlemen, that the observations made on board of merchant vessels with instruments frequently inexact are not to be relied upon in the same degree as those made where the instruments are more numerous and more delicate, and the observers more in the habit of observing. The former, however, from the fact of their being more numerous, give an average result, which may be consulted with advantage; but the observations made on board the ships of the Navy, although fewer in number, are evidently superior in point of precision.

The object of our meeting then, gentlemen, is to agree upon a uniform mode of making nautical and meteorological observations on board vessels of war. I am already indebted to the kindness of one of the members present, Lieut. Jansen, of the Dutch Navy, for the extract of a log kept on board a Dutch ship of war, and which may be quoted as an example of what may be expected from skillful and carefully conducted observations. In order to regulate the distribution of the charts which the American Government offers gratuitously to captains, it would, in my opinion, be desirable that in each country a person should be appointed by the government to collect and classify the abstracts of logs of which I have spoken, through whom also the charts should be supplied to the parties desirous of obtaining them.

The Conference met daily and continued its sessions until the 8th of September. The Conference devoted itself to the consideration of the best form of a meteorological register for the use of vessels of war; every detail was carefully discussed, and two forms of "abstract logs" were adopted, one of which was an abbreviated form for the use of the merchant marine. These forms are practically the same as are in general use to this day. They consist of a series of columns in which are to be recorded the ship's position, the direction and rate of current, observed magnetic variation, direction and force of the winds, barometer with attached thermometer, dry and wet bulb thermometers, forms and direction of clouds, proportion of clear sky, hours of fog, rain, snow, hail, state of the sea, water temperatures at surface and at depths and its specific gravity, and the state of the weather, with an additional column for general remarks.

On a blank page were described the instruments and manner of using them, the corrections for barometer, index error, capacity, capillarity, and height above sea level, when and by whom and with what standard it was compared, the correction to thermometers, and the scale of wind forces, derived from speed sailing by the wind. The Beaufort scale was not then adopted.

The result of this Conference was the establishment of meteorological observations throughout Europe and all over the world on a uniform system, on land as well as on the sea. Prussia, Spain, Sar-

dinia, the free cities of Hamburg and Bremen, Chile, Austria, and Brazil joined the others in this co-operative work. It was decided to carry on these observations in peace and in war, and in case of capture the abstract log was to be held sacred.

At the close of the Congress Maury returned to Washington laden with honors. Many of the learned societies of Europe elected him an honorary member, orders of knighthood were offered him, and medals were struck in his honor. Humboldt declared he had founded a new science.

In 1855 Maury published his work, "Physical Geography of the Sea," which has been translated into German, French, Dutch, Spanish, Norwegian, and Italian. Maury instituted the system of deep-sea sounding, and was the first to suggest the establishment of telegraphic communication between continents by submarine cables. The first cable was laid on the line indicated by him.

On the 20th of April, 1861, the State of Virginia passed the ordidance of secession. Unfortunately, having been born in that State, near Fredericksburg, on January 14, 1806, Maury felt that his native State demanded his first allegiance, and on that day he resigned his commission, turned all the property at the Observatory over to Lieut. Whiting, and went to join the confederates at Richmond. Maury left a number of his writings in unfinished condition, some of which were subsequently published, and when he offered his services to the confederate government he had had no previous arrangement for any position of special honor; but, on the contrary, by leaving the U. S. Navy he made a great sacrifice of his personal ambition in order to do what he believed to be his duty to his native State, and with the loftiest patriotic motives. Only a short time before he resigned he wrote to his friends by all means to stay in the Union, and his resignation was such a surprise, in view of his Union sentiments, that he was accused of all sorts of treasonable and dishonorable conduct, such as the removal of buoys, etc. This was false.

When it became known in Europe that Maury had resigned, the Grand Duke Constantine offered him the post of Superintendent of the Observatory at St. Petersburg to continue his meteorological researches; the French Government also invited him to continue his meteorological work in France, and the Russian and French Ministers carried these invitations by flag of truce through the lines. Maury declined these offers, saying that his country needed his services. He entered the confederate navy June 10, 1861, and in October, 1862, he established at Richmond the naval submarine battery service; but before this was far advanced he was sent to Europe to continue his experiments and to act as one of the confederate navy agents. He invented an ingenious method of torpedo defense with which he sailed to put in operation at Galveston, Tex. Upon his arrival at

Habana he heard of Lee's surrender, and offered to surrender himself.

In June, 1865, he went to Mexico, where he offered his services to the Emperor Maximilian, by whom he was appointed Director of the Imperial Observatory. Maury elaborated the immigration scheme in Mexico and was appointed Imperial Commissioner of Immigration, with the idea of making Mexico a home for ex-confederates, and to develop the resources of that country.

In March, 1866, Maury arrived in England on a special mission, and during his absence Maximilian was overthrown and shot. Maury was received with great honor by scientists and former friends, and in view of his meteorological work they sought to repair his fortunes. He found employment by instructing European officers in the use of the torpedo, and he was offered a permanent position in France. But in 1868 the act of general amnesty having removed all objection to Maury's return, he accepted the appointment of professor of meteorology in the Virginia Military Institute at Lexington, where he was installed in September, 1868. During the last five years of his life he made a meteorological survey of the State of Virginia, and by numerous lectures in different parts of the country he called attention to the importance of meteorological studies in behalf of agricultural interests. Maury died, as he had lived, a Christian, February 1, 1873.

During his life he received the following honors: By the Emperor of Russia, *Knight of the Order of St. Ann*; by the King of Denmark, *Knight of the Dannebrog*; by the King of Portugal, *Knight of the Tower and Sword*; by the King of Belgium, *Knight of the Order of St. Leopold*; by the Emperor of the French, *Commander of the Legion of Honor*; while Prussia, Austria, Sweden, Holland, Sardinia, Bremen, and France struck gold medals in his honor. The Pope sent him a set of all the medals that had been struck during his pontificate as a mark of his appreciation of his labors for science. Maximilian decorated him with the *Cross of Our Lady of Guadeloupe*.

He became Corresponding Member of the "Naturkundige-Vereeniging in Nederlandsch Indie," Batavia, February 17, 1853. "Die Naturfoschende Gesellschaft in Emden," March, 1854. "Société des Sciences des Arts et des Lettres de Hainault," 1854. "Academia Impériale des Sciences de Russe," St. Petersburg, 1855. "Academie Royale des Sciences, des Lettres et des Beaux-Arts de Belgique," Brussels, 1854. "New York Lyceum of Natural History," New York, 1865. "Philadelphia Academy of Natural Sciences," 1858. "Die Gesellschaft zur Beförderung der gesammten Naturwissenschaften in Marburg," 1856. "Historical Society of New Jersey," 1856. "Historical Society of Tennessee," 1857. "Die Gesellschaft für Erdkunde in Berlin," 1858. "Gesellschaft der Wissenschaften," Prague, 1858. "Director del

Observatorio Nacional," Mexico, 1865. "Consejero Honorario de Estado," Mexico, 1865. "Miembro Honorario de la Sociedad Mexicana de Geografia y Estadistica," Mexico, 1865. "Miembro de la Imperial Academia Mexicana de Siencias," Mexico, 1865." LL. D. of the University of Cambridge, England, 1867. He was also a member of several other learned bodies of which the records have been lost. With all these honors Maury's name will ever be held in the highest esteem by mariners of all nations, by the U. S. Navy, of which he was one of its most brilliant officers, and by the American people, who are proud of his achievements.

This Congress of Meteorology must also render to the name of Maury a tribute of most profound gratitude as the founder of the science of meteorology, and the highest honor for his great researches in every department of this science.

Commander J. M. Gillis became Superintendant of the Naval Observatory when Maury resigned, and on the 5th of July, 1862, it was transferred from the Bureau of Ordnance to that of Navigation. Meteorological observations were continued, but the elaborate system of co-operating with the merchant marine was suspended until after the war.

Rear Admiral C. H. Davis became Superintendent on April 28, 1865, and June 21, 1866, the U. S. Hydrographic Office was established, with the duty of making charts and publishing "Sailing Directions" and meteorological information. Very little progress was made with meteorological work during the next five years, beyond the occasional publication of pamphlets on the barometer, thermometer, hygrometer, and general meteorological information in "Sailing Directions."

The Hydrographic Office was reorganized on the 21st of January, 1871, under Capt. Wyman, and five separate departments were created, one of which was the meteorological department, the duties of which were defined to be: "To construct Wind and Current Charts," according to adopted forms, and for this purpose to collect and systematically arrange the meteorological data on hand, or which may be received; to take charge of all log books, track charts, remark books, and such other books, charts, and papers as may be required in the construction of wind and current charts; to prepare and issue blank meteorological journals constructed according to the most recent requirements for the purpose of collecting meteorological data suitable for use in making special and general inquiries into the science; to keep informed on all subjects pertaining to meteorology and physical hydrography.

In 1873 it was decided to again commence the collection of information from men-of-war and merchantmen to accumulate matter for a new edition of Maury's charts, and requests for such data were sent out to the Navy and merchant marine. The method was to collect

data in squares of 5 degrees of latitude and 5 degrees of longitude for each month a vessel might be in one of the squares, and also for each fraction of a month.

Lieut. T. A. Lyons was in charge of the meteorological division and, assisted by a number of other officers of the Navy, he compiled the meteorological data collected, and in the course of three years the office published new sets of meteorological charts for the Atlantic and Pacific oceans, and the work was continued on similar charts for other oceans.

The North Atlantic Meteorological Charts are in 12 sheets, one for each month. They extend from the Equator to N. 60° and E. 10° to W. 85°, with a subchart on the same sheet for the western part of the Gulf of Mexico. In each square are expressed the percentage of the the total number of hours of observations of the true compass directions and force of wind, the calms, variables, rain, fogs, moderate and heavy squalls, gales (all winds above the force of 8, Beaufort scale), the mean barometer, thermometer (both wet and dry bulbs), surface temperature, and the daily ranges of these instruments.

Blank meteorological journals were issued to masters of all merchant vessels who agreed to keep them and co-operate with the office, in October, 1877. These journals are still being kept by masters of merchant vessels, but in 1887 they were superseded by the forms for Greenwich noon observations. The journals are similar to the abstract log books adopted by the Brussels Conference. There are 4,000 of these journals in this office containing data of great value, which are kept available for the preparation of synoptic charts of all oceans. These will enable the office to publish pilot charts of other oceans similar to those of the North Atlantic.

From 1873 to 1883 the work of the Division of Marine Meteorology was conducted on the lines described for the preparation of the new "Wind and Current Charts" on Maury's plans, revised by Lieut. T. A. Lyons. Capt. S. R. Franklin became the Hydrographer on May 17, 1878, and he was relieved by Capt. J. C. de Krafft on July 15, 1880; the latter was assisted by Lieut. Commander C. D. Sigsbee. Commander J. R. Bartlett was appointed Hydrographer June 30, 1883.

To bring the office in close touch with the merchant marine branch hydrographic offices were established in 1883 at New York, Philadelphia, and Boston, and were each placed in charge of a naval officer. Mariners were invited to visit these offices to obtain nautical information, to compare their meteorological instruments, and secure the latest hydrographic publications. These offices issued the log books, blank forms, etc., and were so successful in securing the co-operation of mariners with the office that other branch offices have since been established in all the principal ports of the country, viz: Baltimore,

Norfolk, Savannah, New Orleans, San Francisco, Portland, Port Townsend, and Chicago.

Lieut. S. M. Ackley was in charge of the Division of Marine Meteorology from June, 1883, until June, 1887. In December, 1883, the office commenced the publication of the monthly Pilot Charts for the North Atlantic Ocean. The great practical utility of these charts was demonstrated from the very first, and the work of the division has chiefly been devoted to the publication of these charts. Improvements are constantly being made, and the early issues bear no comparison with those of the present time.

The Pilot Charts are the result of the co-operative work of mariners of all nations, and the number of those who co-operate is constantly increasing. In 1884 there were only 127 observers of the merchant marine, while on June 30, 1893, there were 2,844, besides the observers in the Navy.

Lieut. G. L. Dyer relieved Commander Bartlett as Hydrographer June 1, 1888, and was succeeded by Capt. H. F. Picking in June, 1889. He was relieved by Lieut. Commander R. Clover, September, 1890, and the present Hyrographer, Commander C. D. Sigsbee, took charge June 1, 1893. Ensign Everett Hayden, Marine Meteorologist, was in charge of the division from June, 1887, until May 19, 1889, when Lieut. H. M. Witzel relieved him until January 21, 1892, when Lieut. Commander E. W. Sturdy took charge until December 15, 1892, when he was succeeded by Lieut. W. H. Beehler, at present in charge of the Division of Marine Meteorology. The force in the office consists of four nautical experts (graduates of the U. S. Naval Academy in civil life), viz, Messrs. T. S. O'Leary, R. L. Lerch, L. H. Orr, and H. H. Balthis, a stenographer, and a messenger. This force is engaged on the final work of preparing the data and investigating the various problems for the practical presentation of meteorological information to mariners.

The work is conducted under the Hydrographic Office, and all the divisions in that office are concerned in the work. In fact, the Pilot Charts were originally intended merely as a means for inducing the co-operation of mariners in hydrographic work. These charts are presented to observers in exchange for their reports, and the chart has proven to be such a desirable method of communicating hydrographic and meteorological information to mariners that it has become of the greatest value. The work is, therefore, not so much a scientific study as a practical presentation of facts for the use of practical men. Advantage is duly taken of every new discovery when clearly established, but the investigations are for their practical value and for immediate use.

Under the direction of the Hydrographer, the Division of Chart Construction prints the charts, the Division of Sailing Directions

supplies the hydrographic information for the Pilot Charts, and the Division of Charts gives notice of the charts published, canceled, and extensively corrected. The branch hydrographic offices issue the forms and publications to mariners, receive and forward their reports, compare and correct their instruments, and by personal visits to vessels in port secure the co-operation of additional observers. The office also has the co-operation of the U. S. Weather Bureau, and by the system of exchanges also has access to the reports obtained by the New York Herald Weather Service. The keepers of the lighthouses and light vessels of the U. S. Lighthouse Establishment also co-operate, while there are a number of voluntary observers among the keepers of lighthouses on the coasts of Newfoundland and Labrador,who send valuable and timely reports of the ice movement on those coasts. Voluntary observers in the West Indies and other islands send valuable reports. A number of foreign meteorological observatories and societies correspond with the office, and the U. S. Consular Service renders valuable aid by forwarding reports and bringing the work to the attention of mariners, by which many additional co-operators are secured. The method of current investigation with bottle papers has brought a great many to assist in the work. On the coast of Ireland bottle papers are frequently found, and many very amusing letters are received. In one the finder requested that if the paper was of any value he thought that the office should send him the price of a pair of boots, as he had lost the only pair he had while standing in the tide examining the document.

From this extensive field the office has naturally collected a vast amount of data, so that it is pre-eminently well equipped to continue the work and extend the system of the North Atlantic Pilot Charts to all oceans, and steps to that end have been taken.

The following is a list of reports received: Trade winds, ice, wrecks, fogs, buoys adrift, whales, meteorological journals, storms, Greenwich noon observations, the use of oil to still the waves, waterspouts, ocean currents, Gulf Stream, abstract logs, derelicts, barometer comparisons, curves of self-recording barometers and thermometers, track charts of vessels' voyages, routes of transoceanic steamers, sailing routes, reports of deep-sea soundings, auroras, thunderstorms, electrical phenomena, and general information.

Blank forms are issued for these reports which are forwarded to the Hydrographer, and if not acknowledged by the branch office are answered by him.

In 1883 a weekly supplement, since known as the "Hydrographic Bulletin," was issued and has been regularly published ever since, for the special use of the U. S. coastwise navigators. It has notices about obstructions, dangers, ice, and fog, but does not go into much detail for meteorological information. Two thousand copies are printed every Wednesday.

Upon the receipts of the reports the data are immediately plotted on synoptic charts from which the Pilot Charts are prepared. Reports in foreign languages are translated and utilized. The daily synoptic charts are being prepared for publication.

The Pilot Charts are printed in three colors. The black is a transfer on stone from a regular engraved copper plate of the Mercator's chart of the ocean. The blue data consist of the meteorological forecasts and routes; they are compiled from the accumulated data on the synoptic charts of previous years and indicate the probabilities based upon experience in this month in previous years.

The red text is furnished the day before the chart is published and consists of a review of the weather for the previous month up to the date of publication, the storm tracks, fog limits, drifting ice and icebergs, the position of derelicts, wreckage, etc., and, in the space over the land in the left-hand corner. gives general information of timely interest concerning special reports, storms, currents, use of oil, dangers in the navigation, etc.

Supplements are frequently issued relating to storms, remarkable drifts of derelicts, wreck charts, ocean currents, routes, and the use of oil. Four thousand copies of the Pilot Charts are distributed monthly.

The Pilot Charts have, perhaps, more than any other agency, brought about the general recognition of the value of the use of oil to still the waves, and the masters of hundreds of vessels have reported that they were saved from total loss, with all on board, by the use of oil on seas.

The charts have served to bring about the adoption of regular ocean lanes for transatlantic steamers to minimize the risk of collision.

During the past six months the accumulated meteorological data have been arranged and systematically classified, and a card catalogue has been inaugurated by which all marine meteorological information in all the Department libraries is made immediately available. The system adopted is a classification of all the work in three departments: Meteorology, Oceanography, and Shipping, each of which is divided into a number of subdivisions, and each subdivision again divided into a number of branches, so that every subject is carded in its proper branch of its division of its department.

A new base plate is being engraved for an improved pilot chart which will be designated as a co-operative chart for mariners, in order to emphasize the fact that it is a practical presentation of the meteorological facts reported by co-operating observers.

It is contemplated to largely increase the working force of this division, and it is hoped that the members of this Congress will approve this work and co-operate with the division by giving it the

practical results of their scientific investigations for the use of practical men.

The Congress is requested to consider the advisability of taking at least one observation each day at the time of Greenwich noon. The 2,844 co-operating observers of this office on vessels cruising in all parts of the world take the observations at this time, and if such observations are taken on land as well as at sea, the meteorological conditions all over the world can be seen from daily synoptic charts.

Observations may be taken, in addition, at other times, as at present, and in the Pacific, observations at Greenwich midnight are recommended, but there is urgent need for one observation daily at Greenwich noon by each observer.

In preparing this paper I have consulted: "Founding and Development of the U. S. Hydrographic Office," by Lieut. W. S. Hughes, U. S. Navy; "Memoir of the Founding of the U. S. Naval Observatory," by Prof. J. E. Nourse, U. S. Navy; "Life of Matthew Fontaine Maury," by his daughter; "Maury's Sailing Directions;" "Appleton's Cyclopedia of American Biography;" "Annual Reports of the Hydrographer;" and official records in the Division of Marine Meteorology.

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## 4.—THE METEOROLOGICAL WORK OF THE U. S. SIGNAL SERVICE, 1870 TO 1891.

Prof. CLEVELAND ABBE.

In attempting to give, within a short space, some idea of the general character of the meteorological work of the Signal Service, it will, of course, be necessary for me to present only the prominent characteristics and leave it for the reader to search out minute details from the voluminous publications that have emanated from its own press and from the Government Printing Office. In tracing the development of ideas it would be an agreeable task to specify the individuals to whom the Service is indebted, but, as a general rule, so many were engaged in perfecting the work that had to be done that ideas when once suggested soon became the property of the Service as a whole. A mutual interaction has been apparent between the individuals and the Service in general; its own growth has been their growth. The U. S. Weather Bureau responded first to the immediate pressing daily needs of the business and people of the country, then to the remote needs of climatology, and finally began to develop along those lines of higher science that must be cultivated in order to assure future progress in the art of weather prediction. There is no art without its science. High art implies a higher science behind it.

### GENERAL EPOCHS.

The history of the Service may be divided most naturally into

periods according with the administrations of its successive chiefs. Gen. A. J. Myer, the founder of the Signal Service as a military corps and the organizer of its meteorological work, died August 24, 1880. Adjt. Gen. R. C. Drum was temporarily appointed Acting Chief Signal Officer and was succeeded by Gen. William B. Hazen, who was appointed Chief Signal Officer in December, 1880, and died January 16, 1887. During Gen. Hazen's illness, Gen. A. W. Greely became Acting Chief Signal Officer in December, 1886; he was appointed Chief Signal Officer and confirmed by the Senate March 3, 1887, which position he still holds. On July 1, 1891, by virtue of the Act of Congress of October 1, 1890, the meteorological duties, and the men specially engaged therein, were transferred from the Signal Service to the Department of Agriculture, and Prof. M. W. Harrington was appointed Chief of the newly organized Weather Bureau of that Department.

In general, the administration of Gen. Myer may be said to have been characterized by a remarkable degree of political sagacity which enabled him to control the heterogenous elements out of which he, on the one hand, built up a new military corps in spite of the opposition of the greater part of the officers of the regular Army and, on the other hand, demonstrated the usefulness of this corps by valuable practical work in the interests of every citizen. The value of the military Signal Service to the country was manifested on many occasions, not only during the civil war, but during the subsequent Indian wars, the epidemics of yellow fever, and the labor riots of 1873, to say nothing of its daily activity in weather predictions, flood warnings, storm warnings and other meteorological matters. Notwithstanding this great activity and acknowledged usefulness, Gen. Myer did not live to realize his desire for a permanent and adequate organization of an Army Signal Corps.

The administration of Gen. Drum afforded an opportunity for the younger officers of the Army detailed to special service under the Chief to carry out a number of minor reforms, the need of which had been forced upon them by their personal experience, and the subsequent administration of Gen. Hazen encouraged such progress. The years 1881–'84 were marked by a continued series of meetings of special boards of officers for the discussion of any suggestion that might be made toward the improvement of the Service. Gen. Hazen's own personal predilections were strongly toward the encouragement of the employment of a high order of talent in both the military and the meteorological work of the Signal Service. His attempts to remove dishonest and incompetent men seem to have made for him many enemies, but for his full defense of his course and his strong plea for fairness toward his civilian scientific assistants the reader must consult the volume of testimony before the Joint Commission, published as Mis.

Doc. No. 92, of the Forty-ninth Congress. Like his predecessor, Gen. Hazen also passed away without accomplishing a satisfactory organization of the Signal Corps. Between himself as Chief and the numerous lieutenants who had been promoted from the ranks of the observer sergeants there was still a gap to be filled in by appointments which it seemed impossible to make without exciting the most unpleasant feelings.

During the administration of Gen. Greely the civilian employees of the Signal Service, as well as the lieutenants of the Corps and the lieutenants assigned to the Service from other Army corps, came under the supervision of one who knew every man by name and was intimately familiar with the stations and their work as well as with the relations of Congress to the Service. His first care was to secure the strictest honesty and economy in matters of finance and property, and next to effect the long-desired organization of the permanent Signal Corps, instead of the temporary makeshifts and special details that had hitherto obtained. So long as such organization was wanting the existence of the Corps was threatened and the meteorological work might at any time pass into other hands. As the result proved, however, this last event seems to have been foreordained, and the Act of Congress, approved October 1, 1890, in which Gen. Greely was finally able to accomplish the organization of a permanent military Signal Corps, also provided for the absolute transfer of meteorological work from that Corps to the Department of Agriculture.

We may not be far wrong in summarizing our history by concluding that meteorology was originally cultivated by Gen. Myer as a means of demonstrating the value of his Signal Corps in times of peace and as an argument for its permanent organization; but when it became apparent that the Weather Bureau was even more important than the Signal Corps the wisdom of Congress decided that it should be returned to the Department of Agriculture, where it had been fostered for fifty years, and to the civilians who, as the successors of Espy, Redfield, Loomis, and Henry, represented both the science of meteorology and the men through whose labors weather predictions were first rendered possible.

### GRADUAL EXTENSION OF THE FIELD OF WORK.

The Joint Resolution enacted by the Congress of the United States, February 4, 1870, marks an important epoch in the history of meteorology in America. Others will present to this present Congress some sketch of the long history that led up to this important event. It will be shown that the progressive movement of weather conditions from the west to the east, or from southwest to northeast, had been recognized for a century; that the maps made by Redfield and Loomis, but especially those that were made by Espy and published

by the U. S. Government, had shown the basis on which weather predictions could be safely made; that Ferrel had unraveled the mechanics of the atmosphere; that almost the first use of the electro-magnetic telegraph by its own operators, as it gradually spread from Washington in all directions, was to disseminate knowledge of the coming storms and weather; and that Henry, on behalf of eminent meteorologists, had not only explained how the telegraph could be utilized for weather predictions, but had systematically done this for many years at Washington. Not only these distinguished men, but also Maury on behalf of the Navy, Gen. Reynolds on behalf of the Army Engineer Corps, Maj. Lachlan on behalf of the American Association for the Advancement of Science, and Commissioner Watts on behalf of the Department of Agriculture had successively urged that the Federal Government give authority for storm and weather predictions.

Important epochs are generally determined by the accidental combination of minor actors in the great world around us. The volumes of charts and theories published by Espy and the mathematical investigations of Ferrel had been published for ten or fifteen years, and were rapidly being forgotten, when, in 1868, I had an opportunity to urge and start the "Weather Bulletin" and "Weather Probabilities" at the Cincinnati Observatory. The great volume of data for 1854–'59, published by the Government for the very purpose of demonstrating the movement of storms over the country and of influencing Congress to establish a system of storm warnings, was silently assigned its place on the shelves of our libraries, and had had no further influence, until Lapham, in 1869, drew from it the data for a chart of the storms of 1859. Gen. A. J. Myer has stated that, in sketching out a course of usefulness for the military organization of the Signal Corps, he had, in 1869, presented to the Secretary of War a scheme of weather reports and storm signals, which of course could not, at that time, be carried out for the want of the necessary legislative authority, but this suffices to establish the fact that he was one of the many other independent thinkers in this line of work. Prof. I. A. Lapham, of Milwaukee, a man whose mind teemed with plans for the practical application of his knowledge for the benefit of the community around him, and who was one of the first, in 1868, to respond to my request for daily weather telegrams, desired to secure for Lake Michigan the advantages which he saw could be derived from an extension of the work we were doing in Cincinnati. I had solicited the co-operation of the Chicago Board of Trade, but failed; he, nothing daunted, drew up a petition to the Chicago Academy of Sciences, but on presenting it to the Hon. H. E. Paine for his signature that gentleman took a wider view of the subject and said "this petition should go to Congress, and the weather predictions should be for the whole

country and not for any small section thereof." A few strokes of the pen made the necessary changes; the chambers of commerce in Milwaukee and Cincinnati called upon the National Board of Trade to indorse the petition; Mr. Lapham was indefatigable in securing the co-operation of many local boards of trade; Mr. Paine was exceedingly happy in his management of the bill in Congress. It was easy to make that slight alteration in his bill which assured the approval and support of the Secretary of War. Whatever services both scientists and practical men had performed during the preceding years—however much we may owe to them the knowledge which made the weather predictions a scientific possibility—yet the material embodiment of this idea must be attributed to the statesmanship and political sagacity of Hon. Halbert E. Paine, who, I am happy to say, still lives to witness the development of the work that was then started.

The history of the Weather Bureau of the Signal Service begins with the Joint Resolution, approved February 9, 1870, providing for taking meteorological observations at the military stations in the interior of the continent, and at other points in the States and Territories of the United States, and for giving notice on the Northern Lakes and the seacoast by magnetic telegraph and marine signals of the approach and force of storms.

In January, 1872, and in compliance with the appropriation bill of 1871, reports relative to the stages of water in the rivers were added, and in the following spring, and again in 1873, the floods of the Lower Mississippi were preannounced in general bulletins, so that from this time forward that branch of work became a regular part of the duties of the office.

The appropriation bill, approved June 10, 1872, provided: "For expenses of storm-signals announcing the probable approach and force of storms throughout the United States for the benefit of commerce and agriculture;" and, again, in the same bill provided: "That the Secretary of War be, and hereby is, authorized and required to provide in the system of observations and reports in charge of the Chief Signal Officer for such stations, reports and signals as may be found necessary for the benefit of agriculture and commercial interests."

Thus, in a few years, the Signal Office came to officially include every form of meteorological observation or prediction that could affect the interests of agriculture and of our commerce on the Great Lakes, the oceans, and the rivers. The wide field thus occupied by the Signal Office is summarized by paragraph 3 of the Act, approved October 1, 1890, transferring the meteorological work of the Signal Office to the Weather Bureau of the Department of Agriculture, which reads as follows:

The Chief of the Weather Bureau * * * shall have charge of the forcasting of weather; the issue of storm-warnings; the display of weather and flood signals for the benefit of agriculture, commerce, and navigation; the gauging and reporting of rivers; the maintenance and operation of sea-coast telegraph lines and the collection and transmission of marine intelligence for the benefit of commerce and navigation; the reporting of temperature and rainfall conditions for the cotton interests; the display of frost and cold-wave signals; the distribution of meteorological information in the interests of agriculture and commerce, and the taking of such meteorological observations as may be necessary to establish and record the climatic conditions of the United States, or as are essential for the proper execution of the foregoing duties.

INSTRUCTION IN METEOROLOGY.

The great work thus imposed upon, or assumed by, the Signal Service demanded a large corps of men familiar with both observational, theoretic, and practical meteorology.

I have been told by those who were then on duty under Gen. Myer that immediately upon the passage of the Joint Resolution of February 4, 1870, the officers were ordered to make it their first duty to acquire all the meteorology that was available. Interviews with Prof. Henry of the Smithsonian, Dr. B. F. Craig of the Army Medical Corps, Mr. C. A. Schott of the Coast Survey, Admiral Thornton A. Jenkins of the Navy, Prof. J. H. C. Coffin of the Nautical Almanac Office were frequent. By correspondence with Prof. Loomis of Yale, Dr. Daniel Draper, and Mr. T. B. Maury of New York City, and especially Mr. Lapham of Milwaukee, and myself at Cincinnati, a fund of knowledge, suggestions, forms for observations and telegraph ciphers were acquired, which materially guided in the organization of the meteorological service.

Gen. Myer's next care was for the education of his observers; he therefore added a school of meteorology to his school for instruction in telegraphy and military signaling, located at Fort Whipple, or Arlington, near the City of Washington. This school continued during his lifetime; after his death the name was changed to Fort Myer; it was abolished as a school of the Signal Service by order of the Secretary of War in 1886. At first the instruction at this school embraced courses in military signaling, the meteorological text-books of Loomis and Buchan, the meteorological instructions relating to the special work of the Signal Office, the building and equipment of telegraph lines, and such other duties as officers and men were liable to be called upon to perform.

Next to the instruction of the observer sergeants at Fort Whipple, Gen. Myer's chief anxiety was for the instruction of the officers detailed to his service, and his care in this regard was followed up by Gen. Hazen, who also provided for the instruction of the lieutenants of the Signal Corps, of whom four were appointed in 1881 and 1882, and others subsequently. This instruction began in 1882 with a course of Deschanel's Physics and a wide range of meteorological

literature; it was subsequently enlarged from time to time until, in 1885–'86, a class of six officers attended an extensive course of lectures and instruction supplemented by monthly examinations on the following subjects, i. e., the theory of instruments, chartography, general meteorology, thermodynamics of the atmosphere (Abbe); theoretical meteorology without mathematics (Ferrel); practical meteorology and weather predictions, topographic surveying and drawing (Dunwoody); electricity and laboratory manipulation (Mendenhall). The lectures thus delivered, especially those by Ferrel and myself, were in part embodied in subsequent publications of the Signal Office as appendices to the reports for 1885, 1887, and 1889.

The influence of the Signal Service in meteorological instruction has, however, been felt far outside of its own office. Conscious of the special ability of the active teachers of meteorology in our larger universities, Gen. Hazen requested Prof. William M. Davis, of Harvard College, to prepare a text-book on the subject, which I am told will soon be published, and it will, undoubtedly, be a worthy outcome of his many years of experience. In addition to this it was expected by Gen. Hazen that Prof. Ferrel's "Recent Advances" would serve for the use of the more advanced students, but probably his subsequent "Popular Treatise on the Winds" has been more widely used in this respect.

In 1883 Prof. Frank Waldo improved his opportunities while residing in Germany to compile, at my suggestion, a report on the state of meteorological instruction in European schools, which report is said to have had an appreciable influence in stimulating proper attention to the subject in Germany.

In pursuance of his general policy, Gen. Hazen endeavored to secure the enlistment of college graduates as observers in the Signal Corps, and to provide for these men a course of instruction that should be an advance on that which had hitherto prevailed. In accordance with his orders and for several years, beginning January 1, 1882, lectures were delivered at Fort Myer, principally by Messrs. Abbe, Upton, Waldo, and Hazen; synopses of these are given in the annual reports. Eventually, Prof. Waldo was stationed as permanent instructor at Fort Myer, but his serious illness frustrated this part of Gen. Hazen's plans. In addition to this general instruction in meteorology three of those who graduated from this school, Messrs. Morrill, McAdie, and Maxfield were, in 1882, assigned to the duty of perfecting themselves in matters pertaining to atmospheric electricity, under the guidance of Profs. H. A. Rowland at Johns Hopkins and John Trowbridge at Harvard University.

In 1886 this school of instruction for our observers in their duties was abolished, notwithstanding Gen. Hazen's remonstrance, and its work was relegated to the sergeants at the respective stations, where

it has consisted mainly in the study of Loomis' text-book and of the volume of meteorological instructions and the acquisition of good habits as observers and telegraphers. I think it is a general opinion that the original school of systematic instruction was, in its day, a necessity, and that at the present time its loss is not made up by this instruction at stations or by the very slight insight into meteorology that is acquired by our observers by attendance in our public schools before they enter the Service. It has been a matter of frequent remark that instruction in meteorology has made but slow progress in the schools and colleges of our country since the establishment of the Weather Bureau in 1870; still, progress has been made, and we hope for better times in the future.

After the abolition of the school at Fort Myer it became more than ever evident that the best interests of the Signal Service required it to stimulate the study of meteorology in the High schools and colleges of the United States. Some even went so far as to say that from these sources observers might be drawn already trained for our work, but that expectation has not been fulfilled. On the other hand, by laying out suggested courses of instruction for colleges and universities, by requiring an examination before appointment to any position in the Service, and by encouraging the delivery of lectures and of tentative systems of instruction to be given by members of the Service to High school pupils and the Normal school teachers of Washington, as well as to the students of the Corcoran Scientific school and by addresses to many local schools outside of Washington, Gen. Hazen succeeded in attracting more attention to the Service as an opening for educated young physicists than had ever before been given to it. At the present day the educational systems of the country give an increasing attention to meteorology, but they still need to be supplemented by one or more special schools similar to our schools of astronomy and other sciences where the subject may be pursued with the thoroughness that alone satisfies the earnest student and enables him to do valuable original work.

### EMPLOYMENT OF CIVILIAN EXPERTS.

While attempting to build up a strictly military organization, Gen. Myer had a clear appreciation of the uses that he could make of civilian employees. Having been intimately associated with Paine and Lapham, of Milwaukee, in securing the legislation that authorized the Weather Service, the Chief first secured Prof. Lapham as his civilian assistant, to whom, in fact, the manuscript weather charts and the storm warnings of November and December, 1870, are due. After Prof. Lapham had declined a permanent appointment, on account of his health, I was called to what I then supposed would be a temporary engagement and in June, 1871, Prof. T. B. Maury

accepted a similar position; the electrician, or telegrapher, Mr. G. W. Maynard, was also a civilian appointee. It was all the more necessary to secure a few civilian employees in view of the fact that the officers of the Army, temporarily detailed to Signal Service duty, were liable at any time to be ordered back to their regiments. Up to the middle of 1872 the duty of weather predictions and storm warnings devolved upon the civilians; during the remaining years of Gen. Myer's administration it was equally divided between them and the detailed officers, Lieuts. Craig, Dunwoody, Story, Kilbourne, and Greely. During the administration of Gen. Hazen those who had become second lieutenants in the Army by promotion from the corps of observers in the Signal Service, and especially Lieuts. Powell and Glassford, also became "indications officers," while the special work of predicting tornadoes was assigned to Lieut. Finley. After the appointments of Upton, Waldo, Hazen, Russell, Sawyer, Marvin, and especially of Prof. Wm. Ferrel on August 10, 1882, and Prof. T. C. Mendenhall on January 1, 1885, it came to be recognized that there were multifarious fundamental labors appropriate to the civilian experts besides the making of weather predictions, which, as a purely empirical matter had already been brought to a satisfactory degree of perfection by such experts as Powell, Dunwoody, and Greely. This was especially notable in the experience of the instrument room. No sooner had Gen. Hazen recognized that the latter offered an important field for investigation and had installed Prof. Mendenhall in charge than there began a series of experimental investigations that, as now continued by Prof. Marvin, has powerfully contributed to the accuracy and thoroughness of our observations and methods. But the experiences during Gen. Hazen's administration showed the difficulty of carrying out his policy of a happy combination of military and civilian employees, especially at a time when there was no permanent system of organization as yet established by Congress. The resignation of Prof. Ferrel on September 30, 1886, and the resignation of Prof. Mendenhall, October 30, 1886, left vacancies that were not filled. The death of Gen. Hazen, January 16, 1887, and the appointment, March 3, 1887, of Gen. Greely as his successor, brought other questions of policy to the front, and the younger civilian assistants took up the work that we should have been glad to have seen carried on by more experienced men.

Gen. Hazen's policy of introducing into both the military and the civilian ranks as high a grade of intellectual attainment as was practicable accomplished much for the scientific reputation of the Signal Service and enabled it to accomplish far more for meteorology than could otherwise have been done.

### THE STUDY ROOM.

During 1871–'72 a number of clerks had been assigned to help me

in the numerous studies that I had undertaken, bearing especially on altitudes, winds, rain, frost, storm tracks, river floods, auroras, etc., and my room came to be unofficially known as the "study room." I especially recall Messrs. Fletcher, Fearson, Walton, and Schultze among my faithful clerical assistants. Although this organization was but temporary, yet the experience of the subsequent ten years showed very forcibly the need of a special organization for the purpose of investigating the numerous questions that arose in connection with the daily work of the Service. Other questions, sometimes involving difficult points in meteorology addressed by citizens to the Chief Signal Officer, frequently demanded extensive research in preparing satisfactory replies; besides this there was a general desire, both in and out of the Service, that we should undertake such investigations into the laws of the motion of the atmosphere as would sum up the advances that meteorology was steadily making through the labors of the numerous weather bureaus of the world. To this end Gen. Hazen decided to establish a division to which he gave the name of "The study room," and by his order of January 27, 1881, the general character of the work to be done therein was indicated. At the beginning, three, and subsequently four, young men were especially engaged to assist me in the work of this room, viz, Messrs. Upton, Waldo, Hazen, and Russell; Sergt. G. E. Curtis, who had enlisted for special magnetic work, was eventually assigned and rendered important service. Profs. Ferrel and Mendenhall were afterward added to the civilian scientific staff of the Service, but not to the study room, as such. The many important works carried on in this room are fully enumerated in my appendices to the successive Annual Reports, 1882–'86; my first report was not published as an independent appendix but was briefly summarized by the editor of Gen. Hazen's Annual Report for 1881, and is thus printed on pages 60–73 of that volume. The influence of the study room was felt both in and out of the office inasmuch as it was necessary to study innumerable matters bearing on the instruments and work of the stations. The study of the daily weather map and methods of forecasting was promptly undertaken by the study room, in order to prepare the way for the researches into storms and atmospheric motions that were to be their ultimate work. This, however, I am sorry to say, was within a year discontinued by order of Gen. Hazen, so that from that time forward until the engagement of Prof. Ferrel, there remained no systematic effort on the part of the Service to attack the great problems of dynamic meteorology. Our time, however, was abundantly occupied with duties of an eminently practical nature, as is fully shown in the volume of testimony before the Joint Commission of the Senate and House of Representatives, referred to above.

It is but just to say that the study room had nothing whatever to

do with "speculative studies;" it had no force of clerks and other employees to prepare data for such studies and publications; it had nothing whatever to do with "the elaborate publication of observations and results," except to report against the occasional waste of time and space. In abolishing the study room, as Gen. Hazen was obliged to do in 1886 by order of the Secretary of War, he did not diminish the actual expenses of the office, but only distributed the four men engaged in the study room to other divisions, where their personal work and usefulness continued. The study room accomplished a most important work for the Service in awakening it to the necessity of introducing a higher grade of scientific training and thought and experimental laboratory work; it began to be realized that the Signal Service was no longer able to accept meteorological and physical science as it came from the hands of outside physicists, but that it must itself provide for advanced scientific investigation if the Service was to keep up with the progress of other weather bureaus.

True science is never speculative; it employs hypotheses as suggesting points for inquiry, but it never adopts the hypotheses as though they were demonstrated propositions. There should be no mystery in our use of the word *science*; it means knowledge, not theory nor speculation nor hypothesis, but hard facts, and the framework of laws to which they belong; the observed phenomena of meteorology and the well-established laws of physics are the two extremes of the science of meteorology between which we trace the connection of cause and effect; in so far as we can do this successfully meteorology becomes an exact deductive science. The many branches of meteorological work required of the Signal Service were called practical meteorology, because they related directly to the daily needs of the people, each of whom is more or less interested in the weather. The study room was intended to increase the accuracy of the work of the whole Service, and actually did contribute greatly to that end; its general value to the meteorologists throughout the world has also been testified to abundantly. The bibliography of meteorology, the work on tornadoes and thunderstorms, the treatise on meteorological apparatus and methods, the new psychrometric formulæ and tables, the introduction of the whirled thermometer, the reduction to standard gravity and sea level, the investigation of atmospheric electricity, the preparation of Ferrel's "Recent Advances," and numerous other works initiated and fostered by it, have abundantly testified to the wisdom of Gen. Hazen in establishing the study room. As he himself distinctly stated, the duty of making weather predictions implies that they shall be satisfactory, namely, that they shall be timely and accurate, and this can not be attained without the help of such work as was done in the study room.

THE STATIONS AND THEIR WORK.

That relation between the Signal Service and the science of meteorology, which is of fundamental importance, consists in the character of the observations made at the stations. In reference to this branch of our subject, I need only to say that the whole time of the regular observers was given to the work of the Signal Service, and there was a multitude of duties to engross their attention. The fact that the Signal Service employed hundreds of men whose lives were concentrated upon the maintenance of a complete record of the weather demonstrates the thoroughness of its equipment for this work. It was indeed impracticable to maintain hourly observations, but for many years four simultaneous or telegraphic and three local time or climatic observations were made besides the records of the maximum and minimum thermometers and the continuous record of the wind. With regard to the uniform character and general accuracy of these observations, there can be no doubt that the system of instruction and inspection, and especially the intercomparison of the telegraphic reports that attended the study of the tri-daily weather map, served to prevent and detect any appreciable variation from the desired standard of accuracy; very few instances are on record in which an observer's observations proved to be so unreliable that they had to be rejected. An elaborate system of markings for errors, and of honorable mention and promotion for perfect records, has now these twenty years been operating to weed out the careless and retain the careful observers. In 1891 about two-thirds of the observers had been over five years in the Service and about one-third over ten years. I feel confident, therefore, that the instruments, the observers, and the records of the Signal Service are of the highest order of reliability as compared with meteorological systems of other governments. Reliability and uniformity are especially important when we discuss the question of possible periodical or secular changes of climate, which are, at the most, so slight as to be usually concealed in the uncertainties of the records produced by changes of instruments, observers, hours of observations, methods of reduction, and style of exposure.

With regard to the locations of the stations it must be acknowledged that they were not selected for climatic purposes, but almost wholly with a view to dynamic meteorology and the publication of storm warnings and weather predictions. The Service needed to know the pressure, the temperature, and the rainfall approximately, but it needed to know the winds, and that too the strongest winds, quite accurately. The first great problem of dynamic meteorology is to know the local and the general motions of the air, and, in fact, climatology may also be said to depend upon the same knowledge. As science advances it will be more and more clearly recognized that the greatest possible contribution the Signal Service could have made

to meteorology was accomplished when it wholly divorced itself from the climatology of the country and the cities and put its stations on the tops of the highest buildings and in the most exposed positions, so as to obtain the temperature, the moisture, and the movement of a layer of air 100 feet above the earth's surface over the whole country. It was only after securing this fundamental basis for meteorology that it became proper and rational for the Service to extend its field of observation and descend to the problems of ordinary climatology.

MOUNTAIN STATIONS.

While Gen. Myer was working out the details of the organization and instruction of the men whom he had engaged to perform these new duties, some members of the Geological Survey of the State of New Hampshire, under Prof. C. H. Hitchcock, occupied the summit of Mount Washington as a meteorological station from December 15, 1870, to June, 1871, and so great was the interest in the peculiar conditions of that remarkable point that the Chief Signal Officer consented to maintain it thereafter as a regular station of the Signal Service and called for volunteers to remain there during the extraordinary winter weather. This was at that time the highest meteorological station in the world, and its maintenance for many years and the regular daily publication of its telegraphic weather reports threw a flood of light upon our ignorance of the upper atmosphere; this stimulated, as nothing else could have done, the establishment of similar mountain stations all over the globe.

In 1873 the Signal Service maintained a second special mountain station during the summer time on the summit of Mount Mitchell, N. C., but a permanent station was not established, partly on account of the great expense, but principally because of the importance that was attached to a still more remarkable enterprise of this nature. On July 21, 1873, Sergt. George H. Boehmer was ordered to establish a permanent station on the summit of Pikes Peak, Colo., he having volunteered for this duty. During his first few weeks on that summit he slept in the open air on a large flat rock that is still known as "Boehmer's bed." Eventually a stone building was erected, 17 miles of telegraph line were built down to the lower station at Colorado Springs, and with two men at either station a regular series of observations began which was continued to the end of 1888, and, after a short intermission, is now still in operation. For fifteen years Pikes Peak was the highest meteorological station in the world, and the record brought down from that elevated point will serve in the future to answer many queries as to the condition of the upper atmosphere. The records have been published in full by co-operation with the Director of Harvard College Observatory and at the expense of the funds bequeathed by Robert Treat Paine, himself one of the early meteorological observers and authors of the United States.

In 1881 the Signal Service co-operated most efficiently with Prof. S. P. Langley in carrying out an expedition to the summit of Mount Whitney for the purpose of studying the absorption of the sun's heat by the atmosphere, and the meteorological record brought back from that summit represents the fourth mountain top occupied by the Service.

Special studies in hygrometry were made by myself on Pikes Peak for a few days in 1878, on the occasion of the total solar eclipse, and on Mount Whitney by Prof. Langley in 1881, and again by Mr. Leitzell on Pikes Peak in 1883 and 1884; but the definitive study of this subject was finally made by Prof. Marvin at Colorado Springs and Pikes Peak during the summer of 1885. The results of his own and Prof. Hazen's observations with the sling psychrometer were discussed by Prof. Ferrel in his report of December, 1885, "On Psychrometric Tables."

The summit of Mount Washington is peculiarly subject to high winds, and has afforded Prof. Marvin opportunity to investigate the behavior of various forms of anemometers at this station. The very heavy rainfall on the upper portion of Mount Washington, in connection with the strong winds, afforded a good opportunity to study the effect of wind on the catch of the rain gauge, as well as its effect in distributing the actual rainfall over the surface of the mountain; reports on this subject were made by myself and Mr. Curtis in 1886. The effect of the wind upon the elastic pressure of the air within the room containing the station barometer may be very appreciable during a strong wind, hence the proper exposure of a barometer is a matter of much importance; special experiments on the amount of this dynamic wind effect were made at the Mount Washington station in October, 1886, and are summarized in the subsequent "Monthly Weather Review," as also in the chapter on "The exposure of the barometer" in my "Meteorological Apparatus and Methods."

The regular records of the Mount Washington and Pikes Peak stations have afforded data for numerous studies into the diminution of pressure and temperature with altitude, not only by Dunwoody, Loomis, Hazen, Ferrel, and other American students, but by Europeans, prominent among whom are Hann, Sprung, Dechrevens, Kœppen, Teisserenc de Bort, and John Eliot.

It is evident that both the regular observations and the special studies at these high stations have fully warranted the expense of their maintenance, and if we add to this the fact that their existence has stimulated the establishments of similar stations all over the world, we must recognize that they have served a highly important purpose in meteorology. The high meteorological stations in Europe, on the Sonnblick and Mont Blanc, and the highest balloon ascent, as

recently made in France, and the highest stations of all, as recently established on the Himalayas in India, and on Mount Charchani, near Arequipa, Peru, illustrate the efforts now being made to obtain accurate data from the upper atmosphere, and are the natural development of the work of the Signal Service in establishing mountain stations. It is easily shown that a large class of errors in weather predictions arises from our ignorance of the conditions prevailing above us in a region whose clouds can indeed be studied from below by photography and the nephoscope, but that can be actually reached only by means of balloons and mountain stations. At present the most pressing demand of meteorology is for the development of all these methods of exploration in the upper atmosphere.

### INSPECTION OF STATIONS.

To the meteorologist who desires perfect accuracy in the observations and perfect uniformity of methods nothing is more desirable than the assurance and confidence that results from an occasional inspection of the station. European services generally recommend an inspection once a year, but Gen. Myer's system of organization required complete inspections twice a year. Eventually, after many years of experience and before the transfer to the Department of Agriculture, it was possible to diminish the frequency of inspection to once a year. The inspecting officers were at first the lieutenants of the Army who had passed satisfactorily the course of instruction at Fort Myer, and subsequently the lieutenants of the Corps also engaged in the same work. The wide extent of territory covered by our stations necessitated an amount of traveling on the part of the inspecting officers which would seem excessive to the European meteorologist, but the result attained was a uniformity in the style and excellence of the work unattainable by any other means and, as I suppose, unattained by any other service. The inspecting officers took with them standard instruments and the apparatus for cleaning and repairing; the route passed over by one officer connected with that passed over by another; the observers were examined at each station as to their knowledge of telegraphy, signaling, the cipher code, observations, reductions, methods of keeping the office records, and as to their activity in connection with the outside relations of the office with local business interests. Abuses may have crept into this system of inspection, but it seems to me that it came as near realizing our ideal as human systems generally do, and the high grade of business like punctuality and uniform excellence always maintained by the Service could hardly have been otherwise accomplished.

### LOCAL METEOROLOGICAL COMMITTEES.

In order to bring about intimate and direct relations with the na-

tional business interests, Gen. Myer requested the respective cities to organize committees which should feel themselves, in some sense, responsible to him as the representatives of popular interests and needs. From the chairman of each committee there was usually received an annual or semiannual report, together with many intermediate letters; the committees were kept duly apprised by our observers of the progress of the Service at Washington, and, on the other hand, it gave Gen. Myer timely notice of the character of the work done by the local weather observer. The duties of these committees included both praise and criticism, and, occasionally, some excellent suggestions were received from them; their very existence always demonstrated the desire of the Government to labor in the interests of the people. The Signal Service and meteorological science owe many a debt of gratitude to the support cordially accorded by these committees and the business men whom they represented.

TELEGRAPH WORK.

I must stop a minute to call attention to that feature of the work of the Service which has enabled it to get up its daily weather maps with a celerity and regularity that have always been the wonder and admiration of those accustomed to ordinary commercial telegraphy. Notwithstanding the numerous telegraph wires that connect our principal cities, yet it ordinarily happens that individual dispatches must take their turn, and thereby suffer a delay that may amount to many hours. But Gen. Myer saw plainly that this would never do for the work he had in mind; his experience during the war had accustomed him to attain the utmost possible dispatch, and he demanded this also in his new application of military signaling to the commercial needs of the country. It required much argument to induce the telegraph companies to accept the scheme that he proposed; they entered into it, at first, only on agreement that after a few months' trial it might be modified, and, in fact, such was the friction between the conflicting interests that on the 4th of March, 1871, all telegraphic dispatches were suddenly refused by the Western Union Telegraph Company, and for several days I made weather predictions based on such few reports as we could obtain from our stations through rival telegraph companies. The same trouble occurred in the following year, but eventually Gen. Myer's circuit system triumphed, and it remains to-day a monument to the tenacity of his will. By this simple arrangement the observers deliver their short cipher dispatches to the respective telegraph observers at prearranged minutes; all the men on a specific line of wire, or "circuit," are at hand simultaneously, and any dispatch put on that circuit wire is received simultaneously by all the observers. As soon as any one dispatch of a few cipher words is telegraphed another succeeds it, and thus in a minute a

number of stations have interchanged their reports so far as that circuit is concerned. The next minute another circuit, joining on to the preceding one, is opened, and its own, together with all the accumulated reports, are interchanged. In this manner it is found to require only from twenty minutes to a half hour to interchange reports between all the important telegraph centers of the United States as they converge toward Washington, so that in an hour after the observations are made the observers at all the larger cities begin the construction of weather charts similar to the standard chart that is published at Washington. It is this celerity in getting up a weather chart that enables the Central Office to keep in touch with atmospheric phenomena that are occurring all over the country, thereby immensely stimulating the study of the atmosphere. The weather map tells the forecaster what is going on at the moment, and he hurries to publish his predictions and warnings before the rapidly changing conditions have passed by.

### THE DAILY WEATHER BULLETIN AND MAP.

The general public relations between the Weather Bureau and meteorology began with the publication in the daily newspapers of many cities on November 1, 1870, of the "Weather Bulletin," which contained the details of the observations telegraphed from all observing stations. The Bulletin was at first distributed in full in copies written by the Roger's manifold process; about March, 1872, it began to be also printed as printed manuscript under the title of "Daily bulletin of weather reports with synopses, probabilities, and facts," in which the observed phenomena were collated by districts for comparison with the published weather predictions, and subsequently a small-sized daily weather chart was published by lithography and added to this bulletin. During 1871 the daily bulletin of numerical data was gradually supplemented by the large-sized daily weather map, which was at first produced also by a manifold process, but eventually by lithography, so that in the course of the year 1872 the published tri-daily weather map presented both the data, the isobars and isotherms, the synopses and probabilities. This series of maps was changed to the bi-daily series in 1888 to accord with the new hours of observation and the whole constitutes that contribution to meteorology which has given the Service its greatest popular reputation. At first the weather map covered all that portion of the United States that could be reached by telegraph, and included Montreal, Canada. On November 13, 1871, a system of interchange between the Weather Bureau of the Dominion of Canada and the Signal Service went into effect, and ever since that date as many Canadian telegraph reports as practicable have been received from the Observatory at Toronto, while the United States reports and weather predictions are communicated

to it in return. The need of more reports from the West Indies, especially during the hurricane season, was very deeply felt in 1871, and the establishment of regular stations, manned by enlisted men of the Signal Service, was very exceedingly desirable; but this invasion of foreign countries, and especially the transmission of cipher dispatches presented many objections which could only be overcome by international courtesy. Three stations were opened in 1872 and began reporting in August or September, 1873; three more were opened in 1874. The instrumental outfit was furnished by the Weather Bureau, but the observers were necessarily residents of the respective islands and not members of the Signal Corps. An earnest effort was made by Mr. Maxwell Hall, of Jamaica, to organize an International West Indian Service which would have greatly facilitated the object desired by the Signal Service, but this fell through, and eventually the Service relied largely upon special dispatches from Father Viñes and others, whenever a hurricane appeared to be threatening. During the administration of Gen. Greely an arrangement was made through the Department of State for securing regular observations through the respective U. S. consuls, not only from the West Indies, but also from Bermuda.

Another effort to extend the scope of the area of study, hoping thereby to entirely surround the areas of high and low pressure that appear in our extreme northwestern border, consisted in an arrangement with the Hudson Bay Company, by virtue of which the outfits for five stations were, in May, 1874, delivered to the agent at Fort Garry, Manitoba, it being understood that he would secure regular observations at York Factory, Cumberland House, Fort Chippewyan, Fort Simpson, and Fort McPherson. To our great regret no reports were ever received by the Signal Service from these places, and the country covered by them is still a blank upon the Daily Weather Map of North America. If the manuscript records exist, as I am persuaded must be the case for at least some of these extreme northern stations, and if their fortunate possessor will allow us to copy them upon the appropriate maps, we shall be able to answer some of the questions that prompted the efforts of the Service to secure observations in that distant territory.

To the south of the United States the meteorology of Mexico was almost a *terra incognita;* we knew something of its climatology, but the dynamic meteorology could not be understood without a daily representation of its conditions on the weather map. The United States series of stations stopped abruptly at the Mexican boundary; we saw our "northers" move down into that territory and we experienced their heated terms and their small but intense hurricanes moving up into Texas; for several years Texas and Arizona were filled with Signal Service telegraphic reporting stations, so that there

was scarcely room for them on our map, until we got a clear idea of their meteorology and protected our Southwestern States from the sudden inroad of unpredicted storms; but although the extension of our isobars and isotherms over Mexican territory was desired by Gen. Myer, and even attempted by Gen. Hazen as soon as the international cable was completed, in 1882, from Brownsville southward to Panama and beyond, it is still unaccomplished; it is to be hoped that this important extension of the work of the Service may be carried out by the Weather Bureau under the Department of Agriculture. There is evidently still a great expansion to be desired in the immediate future of the Daily Weather Map.

One of the most notable extensions of the territory covered by the Service consisted in the organization of the system of stations for the study of the climatology and meteorology of Alaska and Bering Sea. The work of the Signal Service in that portion of the United States began with the establishment, in 1876, of observers at Fort St. Michael and St. Paul Island; the men who volunteered to enlist for service in that region were naturalists, who were also engaged in making collections for the use of the Smithsonian Institution. The great desirability of studying the climate of that country added to the desire to understand the origin of our northers and the tracks of storms coming from the extreme northwest, as well as the conviction that it was the official duty of the Service to study the climate and storms of every portion of the United States, led to an increase of the number of stations in Alaska, so that, in 1881, 16 stations were established with about 10 substations, and during the next year the system was still farther extended so as to fairly represent the Aleutian Islands, Bering Sea, and that part of Alaska that is west of the Rocky Mountains.

It is believed that by this extensive system of stations the Signal Service responded to all legitimate demands upon it, and the only remaining regret must be that we have not been able to maintain these stations or to publish in detail the data thus added to our archives. Fortunately, Point Barrow continues to be occupied as a life-saving and meteorological station, but we dare not hope that this will be maintained many years longer.

Those who are especially interested in climatology, both in this country and in Europe, have indulged in criticisms of the Signal Service to the effect that it did so little for climatology, but they seem to forget that the single duty legally imposed upon the Service for twenty years was dynamic meteorology, or actual storm, weather, and flood predictions, and it was only during the last few years, before the transfer to the Department of Agriculture, that climatology became a legitimate and prominent feature of its work. From this point of view we must recognize it as a fact that the first and great

contribution which the Signal Service has made to meteorology was the wide-spread publication of the tri-daily weather chart, based upon simultaneous observations throughout all that portion of the United States, Canada, and the West Indies, that could be reached by telegraph. This series of maps, which was changed to a bi-daily series in 1888, constitutes an immensely rich mine for future research. The fact that the winds are only given to the nearest 45°, and that a crude method of reduction to sea level was for a long time employed, and that the vicissitudes of the telegraph services occasionally cut off an interesting group of stations, may sometimes annoy the student, but on the whole this is a contribution to meteorology proper, considered as the study of the weather, that has not been surpassed by the publications of any other nation. It has given us light where before all was darkness. The three maps daily, at intervals of about eight hours, were an appreciable improvement on the two maps at twelve-hour intervals, and an immense advance over one daily morning map, not only because of the rapid movements of weather changes in America, but also because the afternoon map, at 4.35 p. m , Washington time (9.43 p. m., Greenwich time), and the morning map, at 7.35 a. m. (12.43 p. m., Greenwich time), gave us pictures of the atmosphere in its two conditions of maximum disturbance by solar heat and of minimum disturbance. They did for the daily storm duties that which the maps of monthly means, for January and July, are supposed to do for climatic studies; they presented the extreme conditions into which the atmosphere is brought by insolation during the daytime and by terrestrial radiation at night.

These maps have been reprinted on a smaller scale for the years 1872–'77 and widely distributed. From 75 to 100 copies of the larger size or folio maps have been deposited in such libraries as were likely to take care of them. For the year 1878 Gen. Hazen had entirely new maps drawn, using the manuscript records, thereby insuring greater completeness and freedom from errors of telegraphy; but the expense of the publication of the "Meteorological Record for 1878" prevented its continuance. The policy of the office has for many years encouraged the publication of weather maps at many stations and their free distribution to merchants and students; this policy, aided by a little circular on the practical uses of weather maps, has done more than anything to stimulate the study of the weather changes and has raised up a host of local weather forecasters. There are very many large dealers in agricultural products, shippers, railroad managers, sea captains, planters and farmers who consult the weather map and, to a certain extent, make their own weather predictions when their business interests are pressing. The Service would make a complete return to the country for all it has cost the

nation, if it did no more than to put the reliable and thorough morning weather map into the hands of every citizen who needs it by 11 a. m., daily.

CAUTIONARY SIGNALS FOR WIND AND WEATHER.

The synopses and probabilities that were furnished to the daily press of the country reached the public eye after the lapse of considerable time, nor was it at all certain that they would in any way reach the mariners for whom the service was designed. It was, therefore, necessary to supplement these by a system of visible signals that could be hoisted immediately by telegraphic orders from Washington, and this system of cautionary storm-wind signals was instituted in the summer of 1871, as soon as it was demonstrated that our knowledge of the movements of the storms justified taking that step. The display of the square red flag with the black center, or the cautionary danger signal, marked a passage from the general weather probabilities to the definite special prediction of a specific velocity of wind within a specific time and a small region. The region was defined as within a radius of 100 miles, and the time limit was eight hours. Subsequently, a modification of the signal was introduced showing the general direction of the expected winds, and, again, another modification showing whether the winds would be above or below a certain velocity; at present we have also the so-called information signal, indicating the simple fact that the mariner may, by application to the local officer, learn about some distant storm that may interest him.

A decided advance in our methods of communicating with the public was made early in Gen. Hazen's administration by the adoption of a special signal for the so-called "cold wave." In many localities also special signal devices began to be used by the people—flags and balls, steam whistles and bells, and in Ohio the so-called railroad weather signal had been devised. It became necessary to avoid perpetuating such confusion, and the Service wisely adopted a single, simple system and recommended it for universal use. Some modifications in these signals looking toward simplicity and economy have necessarily taken place, and the system as now adopted seems to give general satisfaction. By means of a few flags, white, blue, and black, the probable local weather for the next day is indicated in every town and almost every telegraph and telephone station in the country, so that any one may know what to expect and prepare for. By its early weather maps, of which in 1891 several thousand were printed daily; by its press reports and predictions that were published daily in every newspaper of the country; by its public weather signals whose flags floated from a thousand staffs, the Signal Service might well maintain "that it collects and distributes an unequaled amount of weather data."

### RIVER FLOODS AND THEIR PREDICTIONS.

Telegraphic reports of the condition of the rivers began to be received by the Signal Service January 1, 1872. This work was so natural and desirable and so easy an expansion of the work originally authorized that there could be no doubt of its propriety. At first it seemed sufficient to publish the reports of stages of water as received at the office, but soon some general indications of probable rising and falling water began to be added to the weather probabilities. The gauge readings, above which a stage of water was considered to be dangerous, as well as the times required for flood waves to descend along the channels of the rivers, as first adopted approximately by me, were revised in a report by Gen. Greely in 1874. The principal and most satisfactory work of the Service relative to the study of the hydrology of the Ohio, Missouri, and Mississippi rivers has been done by Prof. Thomas Russell, whose reports were published in 1890 and 1891, and subsequently. His methods and long range predictions have stood the scrutiny and evoked the highest praises of American and European hydraulic engineers.

### FARMERS' BULLETINS.

In 1873 Gen. Myer made an arrangement with the Post Office by which the midnight synopses and probabilities were telegraphed to many Signal Service printing stations and issued by the first morning mail to all neighboring post offices, where they were displayed as "Farmers' Bulletins." This insured the reception of the predictions by the public independent of the purchase of a morning newspaper. These general bulletins ceased in 1881, and the local flag signals now take their place.

The regular publication of the Service that was taken up next following the daily bulletins, maps, and predictions was the "Weekly Weather Chronicle," which was a short summary of those features of the weather during the week that might be supposed to be of special interest to the agricultural classes. The occurrence of droughts, rain, and frosts were more especially mentioned, the whole occupying about one octavo page. The first Chronicle was published in September, 1872. They were distributed promptly to all boards of trade, chambers of commerce, and weekly newspapers, but were finally discontinued in 1881. These Chronicles were first compiled for the use of Gen. Myer by Sergt. Calver, to whom, I believe, they owed their origin.

That there was a real demand for this weekly publication is evident from the fact that it was revived under the title of the "Weather Crop Bulletin," which was started in May, 1887, and owes its existence to Maj. H. H. C. Dunwoody. This still continues to be a most popular publication; it appears weekly during the growing season and

monthly during the rest of the year, being based upon data collected by the State Weather Service Division. By giving the total sums of temperature and precipitation and the respective departures from the normal this bulletin contributes essential data for the computation of the so-called phænological constants, and may eventually enable us to predict the stage of growth of any crop. Beginning with 1891 this bulletin has been accompanied by temperature and rainfall charts.

THE MONTHLY WEATHER REVIEW.

The need of preserving in some permanent form a brief history of the successive storms and other prominent features of the weather led me early to propose some form of weather review. The same idea was simultaneously suggested by another, who, however, left it for me to execute, and my first review was published at the close of January, 1873; corresponding reviews for the latter half of 1872 were subsequently written out by Mr. Calver for publication in the annual report of the fiscal year 1872–'73. From that time forward until 1883, inclusive, the monthly reviews were annually reprinted as appendices to the Annual Report of the Chief Signal Officer. In 1874 it began to be a serious question what use to make of the great accumulation of records that the office was then receiving from the new voluntary observers. As the result of a strong presentation of the importance of the subject, Gen. Myer ordered me to reorganize the Review on a broader basis, making full use of all available data. This publication still continues to be one of the most important of the Service. For many years there was quite a regular system of rotation in office duties, in accordance with which the officer in charge of "probabilities" or "indications," after a month's tour of duty at that work, took editorial charge of the Review, so that generally the chapters on the storms, or high and low areas, were written in the light of the minute personal study that he had just given to the weather of the month. When this officer did not write these chapters the compilation of the Review fell upon the senior clerk of the Review Division, and among those who did a large share of this work I recall the names of Pearson, Walton, Calver, Berry, and Garriott. The Review consists of text, tabular matter, and charts, and has in many respects been considered as a model for the other weather bureaus of the world; at present the similar reviews for Germany and for India are formidable rivals. It did not at first give in tabular form all the climatic data that is ordinarily required in climatological research, but it is believed that it does so now. For a number of years such climatological data was given in the annual reports in a series of annual tables for each station. After 1884 the climatological tables for the Annual Report were largely extended, so as to respond to the demands of the European International Congresses,

and the "Monthly Weather Review" was treated as a separate publication.

During the years 1878–'83, the Review included a summary of the international work of the office, but subsequently that summary was published separately.

At Gen. Myer's request I sometimes added a chapter of notes and abstracts from current meteorological literature, but this feature of the Review has been only imperfectly developed, and, in fact, quite often omitted as trenching too closely on the province of an ordinary meteorological or scientific magazine.

### ACTIVITY IN MARINE METEOROLOGY.

The vision that the tri-daily maps afforded us of the movement of storm centers and cold waves from the Pacific States eastward across the Rockies, southeastward into the Mississippi Valley, and thence northeast to New England and Newfoundland, daily forced upon me the conviction that many storms affect too large an area to be properly studied on the Weather Map of the United States. As I, therefore, desired observations from the ocean Gen. Myer took a first step toward the realization of this need in June, 1871, by sending to captains and owners of vessels circulars and forms requesting tri-daily, simultaneous, meteorological observations at sea, especially along our coasts. In this way numerous reports were received from the mercantile marine, the correspondence with whom generally took place through the agents of the respective steamship and transportation companies. The collection of observations from vessels lagged somewhat until the resignation of Prof. T. B. Maury in November, 1875, and his subsequent removal to Philadelphia led to his being appointed as marine agent; through his exertions in this place, and subsequently as marine editor of the "New York Herald," the number of our ocean reports was much increased. In 1876 the Secretary of the Navy issued orders, by virtue of which simultaneous observations were received from all vessels of the U. S. Navy. Finally, in 1882, Sergt. Penrod was, at my recommendation, appointed by Gen. Hazen to be marine agent at New York City, and a still greater interest was thereby given to the collection of data from the merchant marine. In 1887 all ocean marine work was relinquished to the Hydrographic Office of the U. S. Navy, and since the cessation of our International Bulletin the ocean data collected by that office has been loaned us for use in compiling the chapter on "North Atlantic Storms," published in our "Monthly Weather Review." Undoubtedly the daily charts and the storm tracks of the North Atlantic, compiled by the Weather Bureau, have given us more light on the subject of ocean storms than all the work of statistical charting done by various nations in continuation of Maury's early work.

By collating the reports of fog and ice on the Atlantic, as has been done systematically in the "Monthly Weather Review," Mr. Garriott has shown the connection of ocean fog with storm centers.

The meteorology of the Great Lakes was long supposed to be fairly well provided for by the numerous land stations of the United States and Canada by which they are surrounded, but Prof. Lapham's annual reports of disasters, reinforced by all subsequent experience, go to show that here is a field of great usefulness. We need more data from the open lake surface, and perhaps the navigators of the Lakes would profit by the educational experience that comes from keeping a minute personal record of the weather and a daily study of the weather map.

In this connection attention should be called to the studies of Prof. Waldo on the measurement of the wind at sea. His observations were made in October, 1882, but were first published in the "Monthly Weather Review" for January, 1887. A more extensive series of observations was made by me on this and numerous other problems connected with ocean meteorology during the voyage of the *Pensacola* in 1889–'90. This subject can be admirably studied by the Lake marine.

### INTERNATIONAL SIMULTANEOUS OBSERVATIONS.

The next step toward the enlargement of our sphere of observation was Gen. Myer's remarkably successful combination of the whole civilized world in the study of the atmosphere as a unit, so that the largest storms could be studied on a scale commensurate with their size and importance. A daily weather map covering at least the whole Northern Hemisphere was needed and was now, indeed, soon to be realized. In July, 1869, I had offered an international exchange by cable daily, between my own and Le Verrier's European system (see *Bull. Hebd. Assoc. Sci. de France*, VI, Aug. 15, 1869, p. 100), and in his report of October 20, 1870, Gen. Myer anticipates the need of international exchanges with Canada, West Indies, and possibly Europe. In 1871–'72 I had many opportunities of showing the importance of a daily map of the atmosphere as a whole, and Gen. Myer was pleased not only with the grandeur of the undertaking as a natural development of Signal Service work, but because it promised to finally give us some knowledge about the beginning and the ending of the many storms that we saw flitting across the American continent. The work seemed likely to be for the benefit of American commerce in whatever port of the world its ships might be, and, therefore, it seemed likely to be heartily indorsed by the people. The complete attainment of this desire would evidently not be possible without the harmonious co-operation of observers on land and sea and of every nationality. It was a work in which all

nations would be likely to co-operate (provided only there could be found the proper central nation—the one friendly power which would be recognized by all as the one with which they could co-operate). As the event proved, the United States was, fortunately, in an independent position that enabled it to command the hearty co-operation of all. After duly weighing the subject, Gen. Myer personally submitted his propositions, first, to the more prominent European meteorological offices individually, then to the International Congress of Meteorology at Vienna, September, 1873, and subsequently to many individual observers. I shall never forget the pleasure and satisfaction that he evinced when, upon his return to Washington, he said to me: "I have followed your advice quite closely; I strictly avoided all discussions and controversies as to theories and methods, and stated that we did not care how the observations were made and reduced, provided only they were strictly simultaneous and promptly forwarded. I have now the assurance that the observations will be made and sent to us by several European weather bureaus, and others will, doubtless, soon fall into rank. I have made the request of each nation individually, asking that it exchange simultaneous observations with the United States. I did not deal with the Congress, except to ask its general approval of the plan. I found all the governments favorably disposed toward the United States, and even more willing to co-operate with us than among themselves."

Undoubtedly the "Bulletin of International Simultaneous Observations," which resulted from these efforts of Gen. Myer, represents the finest piece of international co-operation in scientific work that the world had ever seen, and it is only paralleled by Sabine's work in terrestrial magnetism and by the International Polar Expeditions of 1882–'83. It was maintained with steadily increasing efficiency until it became necessary for Gen. Greely, as Chief Signal Officer, in August, 1887, to announce that the work would be discontinued after December of that year. The published daily bulletins from 1875–'87, the large manuscript maps for the same interval, and the monthly and annual summaries which continued until 1889 constitute by far the most important contributions that have ever been made of data needed for the study of the whole atmosphere. The data in the bulletins and charts were primarily intended as the basis for studies of the dynamics of the atmosphere and not for climatic study as such, and it is a mistake to treat them from the latter point of view. After the general style of the bulletin had been decided upon, and I had organized a clerical force and rules by which the data were all worked over into a homogeneous system in metric and English measures, the heavy work of getting out the publication daily and regularly proceeded with unerring mechanical accuracy and steadiness year after year. The first bulletin was published in July,

1875, for the date of January 1, 1875, and the last in July, 1885, for June 30, 1884, the general rule being that the bulletin of observations on any date should be published just one year subsequently. The published charts accompanying the daily text were probably on too small a scale to be acceptable to special students, but they certainly gave an excellent general view of the condition of the atmosphere from day to day. Owing to the pressure of departmental regulations, as well as to the peculiar views entertained by Gen. Myer as to the policy of the office in reference to scientific studies, this international bulletin was considered as essentially a means for distributing data to the co-operating observers in return for their own observations; it was considered as printed manuscript, not as a public document or published periodical. The monthly and annual summaries of simultaneous observations were first prepared by Lieut. (now Major) Dunwoody; these gave mean values of the pressures, temperatures, and winds at every 2° point all over the Atlantic and Pacific oceans, as read from the daily manuscript map of the whole Northern Hemisphere. The daily chartings were for many years due to the faithful work of Sergt. Otto Schultze. The personal enthusiasm of Lieut. Finley lead him to first plot out the distribution of storm tracks throughout the Northern Hemisphere, the results being published in his "Sailors' Handbook of Storm Tracks," etc., Boston, 1889. A valuable summary is also given by Gen. Greely in Appendix 17, pp. 747–777, of his Annual Report for 1891, where the distribution of pressure and of storm tracks is given both by tables and charts. A simiilar summary on a larger scale, by Maj. Dunwoody, is in press.

Although the international bulletins and charts were widely distributed throughout the world, a copy being sent to each co-operating observer, yet I find that this data has been as yet used by very few persons outside of the Weather Bureau as a means of investigating problems in meteorology. The charts have been used by M. A. Poincaré, of Paris, to locate the positions of the centers of the tropical high pressures from day to day, and he has shown that these move northward and southward, according as the moon is north or south of the equator. He has thus for the first time established the existence of an appreciable fortnightly lunar tide, but, of course, the influence of this phenomenon on our daily weather is problematic and apparently inappreciable.

I must urge on meteorologists the importance of securing and studying the data and maps contained in this great storehouse of accurate observations.

## VOLUNTARY OBSERVERS AND STATE WEATHER SERVICES.

The Weather Bureau of the Signal Service, as it was sometimes called, or the "General Weather Bureau of the United States," as

Gen. Myer allowed it to be called on the title page of the "Monthly Weather Review," not only overshadowed in importance the meteorological work of the Smithsonian Institution, the Patent Office, the Surgeon General's Office, and the Lake Survey, but for a time even threatened to so diminish the interest of these services in meteorological work as to seriously imperil its continuance. In the Annual Report of the Chief of Engineers for 1871 it is stated that the meteorological system of the Lake Survey is discontinued in view of the work of the Signal Service. Surg. Gen. Barnes and Prof. Joseph Henry made an exceedingly advantageous arrangement with Gen. Myer by which the latter received all the monthly reports of those two offices. This was equivalent to concentrating the climatology of the country in the archives of the Signal Service. This occurred in the summer of 1873, and very soon led to a corresponding enlargement of the "Monthly Weather Review," and emphasized the importance of providing a fire-proof building for such priceless original manuscripts. For some years after this there was still a disposition manifested by strict disciplinarians to attach little value to the work done by the several hundred voluntary observers that were thus added to the Service, while on the other hand these unpaid observers, many of whom had kept up their records continuously for ten or twenty years, looked with natural jealousy upon the better paid, regular observers of the Corps, and finding that there was no recognition of their own work gradually became discouraged and many of them dropped out altogether, and that, too, at a time when the needs of climatology really demanded a tenfold increase in the number of observers.

It was in the summer of 1875 that Prof. Hinrichs, of Iowa, sent me a personal copy of the first bulletin of the weather service that he had organized in that State. This was a revival of the State weather services such as had long before existed in New York and Pennsylvania and had been attempted in Massachusetts and Ohio. There could be nothing but advantage, both for meteorology and for the Weather Bureau, in the encouragement of such work as this, and I immediately sent that bulletin with a memorandum to this effect to Gen. Myer. No action looking toward the organization of such services was taken at the time; but in 1881 Gen. Hazen favored the idea of co-operative State weather services. It had become evident that some opening and higher work for the observer sergeants, who had long been in the Service, should be provided, otherwise the Service should lose them entirely. My suggestion was then made that such men be sent to help organize the State services and to represent the Signal Service in the respective States, thereby insuring the harmony which Gen. Myer feared could not be secured.

The first official action of Gen. Hazen was based upon the recom-

mendation of Maj. Dunwoody (see *Ann. Rep. Chief Signal Officer* for 1886, p. 67), and the initiatory letter to the Governors of States was sent out by Gen. Hazen substantially as drawn by myself and Maj. Dunwoody. The steady development of these co-operating State services is due to Maj. Dunwoody, who made a special tour of organization in November and December, 1882, and is now the President of the General Association of State Weather Services. These have been designated as "assisted" rather than as "independent" State weather services. They are organized in intimate connection with, and dependence on, the Central Office at Washington, and they offer the most natural channel for the rapid distribution of local storm and frost warnings; only by means of their help are we able to present in the "Monthly Weather Review" or the "Weather Crop Bulletin" even an approximate idea of the climatic conditions that are of importance to the agricultural interests.

In 1891 there existed 41 State services (at the present time 42), covering every State and Territory, except Alaska; the smaller States have recognized the importance of climatology by the organization of some general form of State weather service. The correspondence with the heads of these services and the care of the data received from them constitute an important part of the work of the Central Weather Bureau. Many of these services have a small appropriation for general expenses from the respective States, others have none at all; all of them deal with their observers as being unpaid and voluntary. Inasmuch as their work is of national interest the Federal Government grants them the franking privilege in all official meteorological correspondence, and the observers receive, individually, copies of the publications of the U. S. Weather Bureau.

## INTERNATIONAL POLAR EXPEDITIONS.

During the years 1875–'80, a movement, inaugurated by Lieut. Weyprecht, of Austria, was enthusiastically supported by all civilized nations, looking to a simultaneous invasion of the polar regions from all sides and at least one year of continuous observations on the meteorology and magnetism of the regions about the north and south poles. Eventually the year July, 1882–August, 1883, was fixed upon for the actual occupation of polar stations. This work harmonized perfectly with the scheme of polar colonization and Arctic research that had always been encouraged by members of the Signal Service.

In 1871 the Signal Service had sent Sergt. Frederick Meyer with Capt. C. F. Hall on the *Polaris;* in 1877 it had contributed observers and apparatus to Capt. Howgate's preliminary Arctic work on the schooner *Florence*, in Cumberland Sound; and in May, 1880, the United States Congress had passed an act authorizing the establishment of a temporary station at Lady Franklin Bay. A preliminary

expedition to that place started out that same year, but returned disabled. Soon after becoming Chief Signal Officer, Gen. Hazen entered warmly into the international scheme for polar research; the appropriation bill of March, 1881, had authorized an expenditure by the Signal Service for the Lady Franklin Bay station, and on the the 11th of that month he assigned Lieut. Greely to that command. The approval of the Secretary of War was given on April 12; the organization was pushed with great dispatch, and the expedition sailed from St. Johns, Newfoundland, July 7.

Even before the special appropriation for the Lady Franklin Bay Expedition had been voted by Congress, Gen. Hazen accepted my suggestion that as the station at Point Barrow had long been famous in magnetic work, and as it was now in American territory, it might be occupied by the Signal Service as a regular station without further act of Congress. Lieut. P. H. Ray, having volunteered, was assigned to the command of the party for that station; this expedition sailed from San Francisco on July 18, 1881.

It is believed that by this prompt action of the Signal Service in manning these two important stations, several European governments were prompted to equally decided action, and the success of the plans of the International Polar Commission was fully assured.

The Signal Service sent relief expeditions to Point Barrow in 1882, and notably to Lady Franklin Bay in the summers of 1882 and 1883, but the latter became disabled and the party was finally brought home by the naval expedition under Capt. Schley in July, 1884.

The large volumes of observations and results of the two Signal Service international polar stations, as well as the work of the *Polaris* and the *Florence* expeditions, have contributed not a little to advance our knowledge of the climate of the immense country lying to the north of the United States; in fact, the great importance of this work becomes more and more evident as other governments publish their own contributions to this year of co-operative polar research, and thus enable us to take a comprehensive survey of the atmospheric conditions at that time.

### GENERAL STUDIES IN METEOROLOGY.

The "Monthly Weather Review" has offered an opportunity for a continuous series of studies of the general phenomena of storms and other meteorological matters. Although its pages are essentially descriptive, yet the successive authors have often found opportunity to introduce valuable suggestions and generalizations. Numerous special studies of hurricanes, tornadoes, and thunderstorms will also be found as appendices in the annual reports. The principal works on storms, published by the Service, have been those of Prof. William Ferrel, as contained in his "Recent Advances" and numerous special

minor memoirs. By a special arrangement with Prof. Loomis in 1872, the daily weather maps were regularly furnished to him in order that he might submit our storms to a critical study independently of any similar work that might possible be encouraged in the Signal Office by Gen. Myer. Twenty important memoirs had already been published by him and were in great demand when, in 1881, Gen. Hazen, at my suggestion, requested Prof. Loomis to revise and summarize his work for publication as a professional paper of the Signal Service; this was about to be printed when Prof. Loomis concluded to publish it as a memoir of the National Academy, in which latter form it has become permanently accessible.

The work in the study room bore directly upon the subject of the movements of the atmosphere, but it was only after the room was abolished that my treatise on "Meteorological Apparatus" and my "Preparatory Studies" were completed and published. It had long been desired that I should prepare a popular treatise that could be utilized in the instruction of new forecasters and which might possibly be edifying to the older ones. The circular on the use of the weather map answered this requirement fairly well in 1871 and the new edition prepared and partly printed in 1884 would have been much better, but its publication was eventually given up. Finally, Gen. Hazen aquiesced in my recommendation that, as a popular text-book for the instruction of the members of the Service, we wait for the publication of the work that was announced as forthcoming by Prof. W. M. Davis. The "Preparatory Studies" of 1889 is a work of a very general and suggestive character rather than specific and didactic, and although it may be as unsatisfactory to some as it was to its author, yet it must be remembered that in this difficult study no one has as yet given us what may be called a complete elucidation of the subject and, therefore, we may note with pleasure the high encomiums bestowed upon these "Studies" by John Elliott, the Meteorological Reporter for India. In 1889 the Chief Signal Officer united with the Secretary of War and the Secretary of the Navy in allowing me to continue these studies by actual experience gained in the cruise of the U. S. S. *Pensacola*, on the so-called "Eclipse Expedition" to the west coast of Africa, during the course of which many beautiful confirmations were recorded of views contained in the treatise which was then being printed in Washington. During 1890–'91, after exploring every possible chance of explaining away the great anomalies that Hann had quoted as opposed to the theories of Espy and Ferrel, I was, with the help of Prof. C. C. Hutchins, fortunately able to show that the cooling of the air by its own radiation will probably suffice to explain the phenomena quoted by Hann, and that this goes a long way toward perfecting our knowledge of the mechanism of storms. About this time I prepared the collection

of translations submitted in February, 1891, and subsequently published by the Smithsonian Institution as "The Mechanics of the Earth's Atmosphere," and with this we may complete our statement of the work done by the members of the Signal Service to advance our knowledge of the mechanical phenomena of the atmosphere as distinguished from the mere statistics of observational meteorology. I have already alluded to the great extension of our field of observation consequent upon the publication of the charts of the International Simultaneous Observations, and we may now say that the Signal Service by international co-operation extended its work in both practical and theoretical meteorology so as to include the whole atmosphere and that this, which was necessary in order to predict American weather from day to day, will become still more imperative when we come to predict the climate from season to season.

### MISCELLANEOUS SPECIAL STUDIES.

Innumerable special studies of subjects bearing on the work of the Signal Service were made during its administration of the Weather Bureau; among these I will enumerate the following, although the list is by no means exhaustive:

*A.—Instruments and methods.*

Observations of uniform accuracy and according to uniform methods must be carried on for many years if they are to contribute to our knowledge of secular changes in climate, or if they are to enable us to compare the climates of different parts of the globe. It is only by the experience of years, guided by the most critical knowledge of the properties of the air, that meteorologists have been enabled to attain to approximate accuracy in the observed data. It is not sufficient to merely set up some apparatus and record the indicated temperature, pressure, and wind, we must allow for all the sources of error that affect the records. The progress of meteorology has been furthered by the Signal Service in respect to each of the instruments ordinarily used, and the present condition of our knowledge of this subject is given in my treatise of 1887 on "Meteorological Apparatus and Methods."

*Self-registers.*—The original scheme of observation for dynamic meteorology, inaugurated November 1, 1870, contemplated three simultaneous observations daily, to be made by the observers in person and promptly telegraphed. But in order to harmonize with the climatological systems already existing, Gen. Myer provided for three other observations daily, at 7 a. m., 2 p. m., and 9 p. m., local time No continuous registration was at that time practicable, partly because of the initial expense of the apparatus, but principally because nothing of that kind was at that time manufactured in this country,

nor could the observers have been quickly trained in the care and repair of complicated apparatus. Every station was, indeed, furnished with a Robinson anemometer whose dial showed the total movement of the wind between two successive readings, and to this extent every station responded to the requirements of a station of the first order, as subsequently defined by the International Committee. Gen. Myer was, however, desirous of introducing continuous registration, provided that apparatus, inexpensive and simple, could be devised by the Signal Service, appropriate to our station use; he, therefore, purchased complete outfits representing the Kew system, as made by Beckley, the Draper system, Wild's system, Hipps' system, Hough's printing barograph and thermograph, and even Secchi's meteorograph; the actual specimen of Secchi's apparatus was that which had been exhibited at the Paris Exposition of 1867. These, and many other fine pieces of apparatus, were all kept in operation for many years in what was known as the "Instrument Room." They constituted a fascinating show to the thousands of curious visitors, while to the mechanicians and observers of the Signal Service they served as a stimulus to the invention of many other forms of apparatus. Gradually it became possible to introduce into nearly all of the stations the simple apparatus known as Gibbon's "single" or "double register," which kept the record of the direction and movement of the wind. Other forms of self-registers were not adopted in the regular work at the stations, excepting maximum and minimum thermometers, until, in 1888, a simple form of self-registering rain gauge was constructed, and in the same year the Richard system of thermographs and barographs began to be introduced. The general subject of self-registers and the corrections needed in order to obtain the best results is treated in my appendix to the Report of the Chief Signal Officer for 1887. In 1891 all the stations occupied by the Signal Service maintained continuous registration of at least two elements, viz, wind velocity and direction, and about one-third kept registers of some other items, such as rain, sunshine, pressure, or temperature; hourly means have been published for a number of these.

*The barometer.*—In order to obtain the atmospheric pressure accurately to within a hundredth of an inch, the Service found it necessary first to compare every barometer with a standard, and then to maintain a monthly comparison between the ordinary and the reserved barometer kept at every station, and finally to establish a system of frequent inspections, which included a special comparison with the barometer of the inspector. The temperature correction was found to require that the station barometers be kept in a special case or box. The influence of the difference of gravitation at the various stations was counteracted by a reduction to standard gravity. The

reductions to a perfect vacuum and to a normal value of capillarity still remain to be investigated, and I have shown that the influence of a high wind on the pressure within the observing room must be determined and allowed for, if not annulled, by my method of exposure.

The published barometric pressures and isobars refer to the ideal condition that would exist if everything were at sea level, and this reduction to sea level has undergone many changes. During the first two or three years tables of reduction, computed by an elementary method appropriate only to small altitudes, were used; this introduced such violent fluctuations into the pressures reported from high stations that it was impossible to use the latter with any satisfaction. As the original readings could not be telegraphed I urged that an annual constant reduction would at least allow the student to perceive whether the local pressures were rising or falling from day to day, and this constant began to be used for high stations in 1872. Shortly after that, however, a method that was still less satisfactory was introduced at all other stations and continued in use until 1881. By that time the custom had been introduced of telegraphing both the reduced and the unreduced readings, and in order to save telegraphic expenses I devised a system of monthly constants that was accepted as an improvement on existing confusion. Finally, Ferrel's formulæ, tables, and methods were adopted in 1886, in which diurnal irregularities were almost wholly eliminated, and the reduction to standard gravity adopted. Unfortunately, however, still further changes were subsequently introduced little by little, destroying the logical beauty of Ferrel's system.

*The thermometer.*—The temperature of the air was at first determined by thermometers hanging inside of a large louvered or double-louvered cage on the top of a roof, but finding that the air that was outside did not flow through the cage with sufficient speed when the wind was gentle, causing the thermometer to follow the slowly-changing temperature of the sides of the cage rather than the change of the outside air, the Service at first enlarged the cage and the louvers; afterward we returned to a single louver and a smaller cage, as recommended by Prof. Hazen, and elevated at least 10 or 15 feet above the roof, and finally, instead of the stationary thermometer, introduced the whirled thermometer inside of the cage. It is believed that on the average the resulting temperatures are now as reliable as those attained by the ventilated thermometer or any other method.

*The psychrometer.*—The stationary psychrometer of Regnault was for a long time used with its wet bulb covered with too thick a layer of cloth or wicking. The first improvement was to substitute thin muslin, and the next was the computation of tables in strict adherence to Regnault's formula, which demanded a careful consideration of

the local barometric pressure. This was an appreciable and annoying labor; but it had long been evident to physicists and meteorologists that Regnault's formula, and the psychrometer as used by him, was a very unsatisfactory method of determining atmospheric moisture. Even in his own day his countrymen, Bravais and Arago, had used the whirled psychrometer as a decided improvement. Espy had also used the sling psychrometer, while the Italian, Belli, had recommended the ventilated form. In 1868 Dr. B. F. Craig, of the Surgeon General's Office, had introduced a combination of the two methods. On behalf of the study room Prof. Upton was asked to examine this subject, and the work was also taken up by Prof. Hazen. I had attempted to determine the effect of barometric pressure by some observations in 1878 at Pikes Peak, but it was now decided to thoroughly investigate the influence both of ventilation and of barometric pressure. The observations were made by Profs. Hazen and Marvin, at Washington, and by the latter at Colorado Springs and Pikes Peak, and the theoretical investigations were done by Prof. Ferrel, whose resulting tables for use with the whirled psychrometer were adopted in 1886. Prof. Ferrel showed that the barometric influence becomes inappreciable when the thermometers are whirled or ventilated with sufficient rapidity, and under this condition his tables give the atmospheric humidity with sufficient accuracy.

*The anemometer.*—The Robinson anemometer, as made by Green and originally adopted by Gen. Myer, has remained almost unchanged as to its style and dimensions, although there have been some variations in the weight of the axle and cups; when well oiled, the instruments, as received from the maker, agree with each other within 5 per cent in ordinary winds; but investigations have shown that the factor 3, originally adopted by Robinson and introduced into the mechanism of the dial, may be much too large for winds of less than 50 miles hourly velocity, and probably still more in excess for higher velocities. The exact value of this co-efficient has been computed by Prof. Marvin from observations on a large whirling machine; he has shown that the inertia of the revolving axle and cups causes them not only to lag behind the variations of the wind, but to record a velocity that is too high on the average when the wind is gusty. By adopting much lighter patterns the Bureau will materially improve its wind records.

*The wind vane.*—At first thought the simple wind vane would seem to be incapable of much improvement. It is necessary that the staff should be vertical, and that the vane should turn with the least possible friction and yet with considerable steadiness, such as is secured by taking advantage of the viscosity of oil. The method by which the vane records its position electrically on the distant cylinder is an adaptation by Sergt. (afterward lieutenant) Gibbon of similar methods used in Europe, and has worked with satisfaction since 1872.

The tail of the wind vane spreads horizontally in a V shape, a form that was first recommended by Parrot in 1797, but the correct explanation of the mechanical principles involved in the action of this vane seems to have been first given in 1887 by Mr. G. E. Curtis, of the study room.

*The rain gauge.*—The amount of water caught by the rain gauge has always been accepted as a true record of the rainfall at any locality, and yet it has always been known that rain gauges distant from each other a few feet, horizontally or vertically, often record very different amounts. These differences have generally been treated as though they were accidental irregularities in the rainfall. It is, however, demonstrated that these irregularities are almost wholly due to the force of the wind and the character of the rain, and that they should either be allowed for by a system of numerical corrections, or that they should be annulled by using shielded or protected gauges. The latter method is now being largely used in Europe, but in order to secure some method of deducing from past records, a rainfall that will be comparable with that to be recorded in the future by the new method, both systems should be carried on simultaneously at each station for several years.

*The actinometer.*—The total amount of heat that we receive from the sun is a fundamental constant in meteorology, and the total amount of sunshine, plus the reflected radiation that a plant receives from the clouds and surrounding landscape, is a fundamental constant in climatology. The various forms of actinometer, and especially the black and bright bulbs in vacuo, were carefully studied by Prof. Ferrel, both theoretically and experimentally, preparatory to the introduction of these instruments into use at our stations. This was, so far as I know, the first adequate study of the subject from a physical point of view, and resulted in showing that actinometry is not yet sufficiently advanced to warrant its introduction at Signal Service stations. While thus saving the Service from further unprofitable work and expense, I may add that some modifications that have been made by us in the method of observing, and some criticisms by Prof. Chwolson, of St. Petersburg, seem to me to have already advanced the subject to a higher stage, such that regular work by the Weather Bureau will soon become practicable and important.

*Evaporation.*—Regular observations on evaporation began to be made by the Signal Service in 1885, after Prof. Russell had investigated the behavior of the Piche evaporometer. His investigation of the influence of the wind on the indications of this apparatus and his estimates of the general depth of evaporation throughout the United States are given in the "Monthly Weather Review" for September, 1888, and mark out the path that must be pursued by future investigators in this line.

*Spectroscopy.*—The absorption bands of the spectrum, so far as they are due to atmospheric moisture, were said to be highly important to the weather predictor, and twelve of the stations were entrusted with this class of work as a first attempt. The results, as reviewed by Mr. Upton, show that the observers needed special training and that the apparatus needed further improvement before good results could be attained. Two spectroscopes, specially made for Prof. C. S. Cook, promised to do better work, and the Bureau, therefore, awaits the further development of this subject by the physicists.

*Nephelometry.*—As some simple apparatus for determining the direction of motion of the clouds is much needed, we have devised a nephoscope for use at sea that has stood the test of much usage; the same general construction will also apply to those that are be to used on land.

*Earth thermometers.*—The determination of the temperature of the soil is of importance to both agriculture, meteorology, and vulcanology. The apparatus for this purpose, perfected by Prof. Mendenhall in the Physical Laboratory and Instrument Division, became practically available for this work in 1886.

*Seismoscopes.*—By co-operation with the Geological Survey the Signal Service, in October, 1884, undertook to assist in obtaining better observations of the slight earthquake tremors that frequently occur throughout the country. In August, 1886, the great Charleston earthquake gave a further stimulus to this work, and the seismoscopes, designed by Prof. Mendenhall, were widely distributed after that time to those who volunteered to care for them.

*Electrometers.*—In order to provide for observations of atmospheric electricity at many stations, some modifications of the Thomson electrometer were introduced by Prof. Mendenhall, and the instruments that have been made in accordance with his designs have been very successfully used.

### *B.—International standards in meteorology.*

The relation of our meteorological standards of measurement to those of Europe and their permanency, so as to insure the mutual intercomparability of the work done in all places and at all times, has been a matter of great solicitude. Boards were appointed by Gen. Hazen in 1880 and 1881 to investigate this subject, and the Signal Service has since then made numerous excellent contributions to meteorological apparatus and methods. It was one of the first duties of the study room to pay careful attention to this subject, and in the summer of 1882 Prof. Thomas Russell was appointed, as one familiar with accurate thermometer work, to establish a thermometric standard for the Service. By adopting the air thermometer and by comparisons with Prof. Rowland's apparatus he at once put us on a

par with the International Bureau of Weights and Measures, and since that date our standards have been practically identical with those at Sevres.

During a part of the years 1883–'85, Prof. Waldo being absent at his own expense in Europe, the Signal Service improved this opportunity to secure an international comparison of barometers and thus contributed not only to the perfection of its own standard of barometer, but to the establishment of a truly international standard. Those who are familiar with the subject recognize that there was not then, and in fact is not now, any absolute standard in barometry; the so-called normals at Paris, St. Petersburg, London, and Berlin differ among themselves by quantities so much larger than the probable errors of the comparisons that it is evident that some unknown source of error still remains to be accounted for. The standard adopted at Washington agrees sensibly with that of the International Bureau of Weights and Measures. The Signal Service was the first in the world to adopt the reduction of the barometer to standard gravity, and although it afterward retraced this step, still it will ultimately inure to its credit to have led the way in this important reform.

### C.—*Standard time.*

Precision of time at all stations was absolutely demanded by the Signal Service system of work, and the great annoyance caused by the uncertainties in the local standard of time used by our voluntary observers and in a few cases by our regular observers had been peculiarly felt by myself in studies upon the phenomena of thunderstorms, earthquakes, auroras, and meteors. In order to remedy this it was necessary to effect a complete reform in the popular mind as to the desirability and possibility of greater uniformity and accuracy, and especially to do away with the old conservative ideas as to the need of a local time peculiar to each town and city; the writer, therefore, recommended to the President of the American Metrological Society the appointment of a committee on standard time, of which he was made chairman, in May, 1875. My ideas were heartily indorsed by the action of the American Association for the Advancement of Science and of the Yale College Observatory, and especially by President Barnard of Columbia College, and subsequently by Sandford Fleming, of Canada. In fact the matter was one on which I had already taken action as director of the Cincinnati Observatory in 1868. The final report of our committee was dated May 20, 1879, and is published in the proceedings of the Metrological Society. It recommended the system of meridians that is now in general use. It was evident that the most important step must next be taken by the railroad and telegraph companies, and after securing the hearty sympathy of Mr. W. F. Allen, Secretary of the General Time Convention of Railroad Offi-

cials, the committee purposely left the further active work largely in his hands, the principal assistance that the committee rendered him being confined to such wide-spread newspaper notes as would prepare the public for the change that was to come.

In October, 1883, at the meeting of the Railway Time Convention, Mr. Allen secured a favorable vote adopting the new system of standard hour meridian, counted from Greenwich, but it was still necessary to induce towns, cities, states, and people to give up the old local and adopt the new standard times, and the initiative in this part of the reform was taken by the Harvard College Observatory at a moment (October 7, 1884) when the director, Prof. E. C. Pickering, was absent from the country and when it was important that action should be taken at once. This prompt action was, I believe, greatly facilitated by a telegram from Gen. Hazen to the President of Harvard College, urging that he fail not to take the lead in this great reform. A few days later the International Congress on Standard Time, called together by the United States Government, met in Washington and commended the system of hourly meridians for use throughout the whole world. Since January, 1885, the Signal Service has kept its records on seventy-fifth meridian time, and only in so far as it has had to deal with the local public has it adopted the standard zone time in use in respective cities. Americans will be gratified to realize that this system of hourly zones, counting from Greenwich, has rapidly won favor everywhere throughout the globe, and the legislation that has just been enacted in Europe establishes the hope that before the close of 1893 the railroad and telegraph companies throughout the world will all be using either Greenwich time or something different therefrom by a whole number of hours. Undoubtedly this system, which originated in the Signal Service and the American Metrological Society, will eventually be adopted by the towns and the people throughout the world as thoroughly as it has been in America.

Although European climatologists have objected to the use of zone time by observers, yet there is scarcely any difference of opinion as to its importance in advancing the simultaneous work required in weather prediction and dynamic meteorology; excepting my efforts in Cincinnati in 1869 the Signal Service has been the first to recognize the practical importance of this simultaneity of observation.

In 1878 some of the Weather Bureau observers had been allowed, at the request of local meteorological committees, to co-operate with the Naval Observatory and Western Union Telegraph Company in caring for the public time balls that were dropped at noon, and in March, 1881, General Hazen issued a memorandum explaining the condition under which the the Signal Service would further co-operate with any city that desired to maintain a time ball, his principal object being

to secure accurate time and the diminution of the confusion in local standards.

In 1882 Prof. Waldo was set to work on the problem of standard time, the object being to assure ourselves that all regular stations throughout the country were employing a uniform standard, accurate to the nearest second. A remarkably fine clock was built by the American Watch Company at Waltham; it was in a hermetically sealed brass case in order to obviate the influence of changing atmospheric pressure and any possible magnetic influence on the steel pendulum. A pier was specially prepared in the subbasement of the War Department in a room whose temperature variations were slight and were partly annulled by a self-controlling heating arrangement. The performances of this clock were so perfect that the irregularities of the noonday time signals soon became apparent and furnished a final argument for our action relative to a proposed system of distribution of standard time. As every observatory must rely upon its clock rate during long periods of cloudy weather, a circular was sent to all those who were at that time distributing standard local times asking that they telegraph daily a signal representing the respective standards; all these were to be recorded upon the chronograph of the Signal Office; the results of the intercomparison of these signals among themselves were to be immediately telegraphed back to the respective centers, which were thus enabled, to send out time signals accurately conformable to the mean of all. The increased accuracy and uniformity that would thus be secured for the time balls and railroad time signals throughout the country would undoubtedly be appreciated by horologists, navigators, and meteorologists, and possibly by the astronomers themselves, and were very necessary for the observers of earthquakes, auroras, terrestrial magnetism, and atmospheric electricity. Favorable replies were received from all to whom this circular was addressed, but as the plan of co-operation was never actually carried out we can only hope that some one more fortunately situated will, in the future, accomplish that which the Signal Service had planned and prepared to perform.

*D.—Studies of storms and weather.*

Notwithstanding all that had been done by meteorologists before the beginning of Signal Service work, still our knowledge of the atmosphere was of a very elementary order when the Signal Service began the publication of its weather probabilities, and the writer at once began the comparison of our Weather Maps with current ideas as to the causes and mechanism of the storms and weather. At Gen. Myer's request a short circular was prepared in April, 1871, on the Weather Map, with the idea that every one could be stimulated to study the map and learn to make his own predictions, or at least

learn to interpret the general official probabilities. With steadily accumulating data we got at the connection between the motions of storms and the areas of rains, of rising temperature, of ascending winds, of melting snow; even the slight diurnal variations in this motion were already known in 1872, although the table of data was first published in my preliminary studies of 1889. In 1873 the writer suggested and prepared the charts of statistics of storm frequency and climatic characteristics, published in "Walker's Statistical Atlas," in which, among other things, the region of special storm frequency in Kansas and Nebraska was first established. Charts of the typical storm paths were prepared under Lieut. H. L. Jackson for the Annual Report of 1874. The general statistical study of the subject having been relinquished to Prof. Elias Loomis, the members of the Signal Service made no special contribution to the general theory of storms, except through brief notes in the "Monthly Weather Review," or in the annual summaries of progress in meteorology. But our work had aroused the interest of Prof. Ferrel, who had for some years confined his studies to the subject of the tides, but who now began to again devote his attention to meteorology, publishing his results in various journals and in the three memoirs that were printed by the Coast and Geodetic Survey; finally, his engagement with the Signal Service in 1882 resulted in the publication of his "Recent Advances," as well as many minor reports, so that through his labors the Signal Service contributed greatly to the progress of meteorology. Meanwhile the general statistics of storm frequency and storm tracks were worked up by Lieut. Finley and published in the volume of charts for the use of navigators, under the title "The Sailors' Handbook of Storm Tracks, Fog, and Ice," Boston, 1889. This work is apparently not known as widely as it deserves to be. The charts of international simultaneous observations furnished Lieut. Finley much of his data, but they were especially made the basis of the statistical tables and charts published by Gen. Greely in his Annual Report of 1891, and of those that have just been published by Maj. Dunwoody. The most elaborate studies of the correlation of areas of high and low pressure, with the meteorological conditions, have been those made by Prof. Thomas Russell, and partly published in the Annual Reports for 1889, 1890, and 1891. The physical papers contained in my "Short Memoirs," of 1877, the popular work entitled "Preparatory Studies," written in 1889, and the mathematical memoirs translated in my "Mechanics of the Atmosphere," dated 1891, may finish this list of general works on the movements and the storms of the atmosphere.

Studies of special hurricanes will be found in the earlier volumes of the annual reports and in the successive "Monthly Weather Reviews;" while these are largely confined to the presentation of observed

facts by charts and tables, yet they often contain suggestions and working hypotheses that are worthy of consideration. The opinions of experienced persons, as reflected in the "Monthly Weather Review," mark the gradual progress of our ideas of the mechanics of the atmosphere.

Special studies of individual tornadoes were for many years a favorite, and, in fact, a necessary step toward gathering accurate data. These special reports began, I believe, with a rather elaborate study by Sergt. James Mackintosh, of the Iowa and Illinois tornado of May 22, 1873. The extensive labors of Lieut. John P. Finley, and the increasing literature of the subject, are shown in Mr. Fassig's bibliography, while the care with which the Service predicts the conditions favorable for such severe local storms shows the practical value of the thought that has been spent on this subject.

The study of frosts, especially as to their location in connection with areas of high and low pressure, very early claimed the attention of the Service, and a special study of the hygrometric conditions favorable for frosts was made by Lieut. Allen in 1890. It has rarely happened, since 1872, that any early or late frost injurious to tender crops has occurred without some premonition.

The first cold waves in the autumn of 1871, and the attendant northers flowing over Texas to the Gulf, afforded a fine illustration of the value of the tri-daily weather map in elucidating what had hitherto been treated as two distinct phenomena. It was not in those days possible to decide between the conflicting explanations as to the origin of this cold air. Prof. Loomis maintained that there was a direct descent from above, but the students of thermodynamics maintained that in such a case the air must be heated, as in the "fœhn" and chinook winds; this point was, I think, settled by the experimental research completed in 1891, by Prof. C. C. Hutchins, of Bowdoin College, who, at my request, measured the radiation of atmospheric air, from which it appears that descending air may cool by radiation faster than it is warmed by compression. Meanwhile extensive studies on the statistics of areas of high pressure were compiled by Lieut. Woodruff, and especially do the statistical analyses of highs and lows, by Prof. Russell, give us the best of basis for further advance in our knowledge and prediction of cold waves.

The hot winds that occur from Texas to Kansas were specially studied by Prof. G. E. Curtis in 1887. Subsequently I had occasion to trace them back to their ultimate cause, namely, the dynamic heating of descending air currents, superadded to the insolation of a hot, dry soil; this conclusion was first embodied in an official letter from the Signal Office to Senator Plumb, of Kansas, and has been confirmed by the statistical study of the Signal Service observer, Dr. Cline, at Galveston, Tex.

### *E.—Climate and crops.*

In addition to the daily predictions and their dissemination among the agriculturists, the Signal Service has made numerous special studies of the relation between climatic conditions and the principal crops of the country. The principal steps in this direction have been as follows: the inauguration of systems of observers and reports for the cotton-belt region and sugar districts; the publication of tables by Maj. Dunwoody, comparing rainfall and temperature with crop production; the reports of Gen. Greely on the rainfall and climate of the arid regions, of Nebraska, and of the Pacific slope and western States and Territories; the report of Lieut. Glassford on the rainfall of the Pacific slope and on the climates of Arizona, New Mexico, California, and Nevada; the report of Lieut. Greene on the interior wheat lands of Oregon and Washington. But the most popular publication has been the "Weather Crop Bulletin," compiled by Maj. Dunwoody, and published weekly during the summer season since May 1, 1887, and which gives charts of rainfall and temperature and the departures therefrom, as well as a brief summary of the condition of the crops. In March, 1891, and in view of the approaching transfer of the Weather Bureau from the Signal Service, I was ordered to prepare a summary of our knowledge of the relation between the climate and crops of this country. The resulting preliminary report of June 30, 1891, forms, as I believe, far the most complete collection that has yet been made of our knowledge of this subject, as derived from experiments, observations, and statistics, concluding with a review of all that is known as to the yield per acre for each important crop since 1860.

From 1868 to 1878 the destruction of crops caused by grasshoppers, or the so-called locust, attracted increasing attention in the Western States, and the Signal Service co-operated in the collection of data and the dissemination of methods of relief from this pest; a method of predicting the time of hatching with considerable accuracy was submitted by me to the U. S. Entomological Commission, and promises to be practically useful when the necessary observations of the temperature of the soil are at hand.

### *F.—Exploration of the upper atmosphere.*

Under this title we must include not merely the observations on mountain stations but especially the efforts to utilize the balloon in determining the conditions that prevail high above the earth. This latter work began with a report by myself to Gen. Myer in December, 1871, urging the importance of the subject and submitting a plan for the utilization of small free balloons, and also presenting a summary of such results as could be derived from about 100 of the ascensions that had been made up to that time by the aëronaut, Prof. S. A. King.

Through the enthusiastic co-operation of Prof. King the Signal Service was subsequently enabled, at slight expense, to send observers on aërial voyages as follows: 1872, Mr. Schaeffer ascended with Mr. King from Rochester; 1877, Mr. Ford went up at Nashville on April 3, June 18 and 19; 1882, Mr. Upton went up from Minneapolis, and a few weeks later Mr. Hass-Hagen ascended from Chicago; in 1885 an arrangement was made with Prof. King by which a number of ascensions were made from Philadelphia whenever ordered by Gen. Hazen. In accordance with this plan five ascents were made, four of them in the special interest of meteorology, with Mr. Hammond as observer, and the last one in the special interest of military signaling and photography. Through the kindness of another aëronaut, Mr. Allen, similar privileges were by him accorded to Prof. Hazen, who has made several ascensions. The valuable results of all these aërial voyages have been published in the "American Meteorological Journal."

*G.—Clouds and photography.*

In 1870 there were but few who had followed in the footsteps of Espy in his minute study of the clouds and their teachings. The forms for the use of observers, as distributed by the Smithsonian Institution, had indeed called for separate observations of the upper and lower clouds, but only a small percentage of the observers gave especial attention to this work. Climatology calls for the temperature, the moisture, and the winds, and these were the matters most generally observed. Fortunately, some newspaper paragraph concerning Espy's theories had caught my eye when a boy, and, as a result, I had accumulated numerous studies of the forms and motions of clouds, made in New York City in 1856, in Connecticut in 1857, at Lansing, Mich., in 1858, and at Cincinnati in 1868–'70, and had already on several occasions sought to stimulate professional photographers to secure pictures of the clouds. Of course, I soon found opportunity to urge the importance of the subject upon Gen. Myer, and the forms for the use of our observers, as well as our system of cipher code, were modified so as to more fully provide for both upper and lower clouds. The use of a mirror for observing the directions of the clouds was also spoken of, but did not at that time come into use. The most interesting step taken by Gen. Myer was the purchase of a large camera and the employment of Mr. George W. Rice as a civilian photographer. Work was at once begun in 1871 upon cloud photography, and a number of Mr. Rice's pictures were for a long time on exhibition, but his employment was only temporary, and after it ceased the apparatus remained unused for many years; it was, in fact, too large and costly to be economically used in this work, which was, necessarily, in its experimental stage. As we progress in our knowledge of the details of the motion of the atmosphere, the want of

accurate photographs becomes more and more felt, and the amateur photographers who have developed special and successful methods for cloud photography are now beginning to make valuable contributions to meteorology. This is a field in which the best results can be attained only by the co-operation of two or more photographers located within a few miles of each other, and, of course, such a happy combination is not likely often to occur. The perfect development of cloud photography will perhaps be best attained by the formation of a special association or club among those devoted to the subject. Such photographs not only preserve for future study the more beautiful forms among the clouds, but will give us typical forms of motion that elucidate the movements in the upper strata of air. The photographic camera will eventually become an important adjunct at every meteorological station of the first order, where we are required to register, as far as possible, all atmospheric phenomena. An intense interest concentrates in the efforts to obtain photographs of waterspouts and tornadoes. The Signal Service has collected every known specimen of such photographs, but it is said that there are only one or two that were not so altered by the "artistic" photographer as to have lost their value to the meteorologist. The difficulty of obtaining a legible photograph under a cloudy sky is such that only a rare combination of favorable circumstances will ever secure a photograph of these interesting whirls; but a very great contribution to our knowledge may be obtained if, in ordinary cases, the photograher who sees a tornado or whirlwind will make several successive pencil tracings of the clouds, the débris, and the horizon, as depicted on his ground glass, or a corresponding sheet of oiled paper, or a transparent film of celluloid. Many methods of using cameras without photography have been devised for the use of meteorologists, and most of them are described either in my manuscript reports of 1872 on "Methods of Observing Clouds," or in my treatise of 1887 on "Meteorological Apparatus." The very convenient marine nephoscope, for use in connection with the ordinary ship compass, which was first constructed in 1889 for my use on the U. S. S. *Pensacola*, was the latest contribution of the Signal Service to the methods of observing clouds.

*H.—Atmospheric electricity.*

In 1872 Prof.. Lapham made a report to the Chief Signal Officer upon the observations made by Dr. Wiclizenus on atmospheric electricity at St. Louis, Mo., and recommended further work in this line, but the difficulties attending this class of observations and the great uncertainty as to its value to the work of the Service necessitated a long delay before the matter could be properly taken up. In 1881 the writer recommended to Gen. Hazen that the Service could do

nothing of value in atmospheric electricity without securing the hearty co-operation of the professional electricians and schools of electrical engineering. Through the kindness of Prof. John Trowbridge of Harvard College and Prof. Henry A. Rowland of Johns Hopkins University, an arrangement was made by which such observers as Gen. Hazen might select were allowed to freely enter upon courses of special instruction, and room was provided for any apparatus that the Service might desire to set up. In the summer of 1882 Messrs. Morrill, McAdie, and McRae were assigned to instruction and work in electricity under Profs. Rowland and Trowbridge. After the appointment of Prof. Mendenhall, electrical work was principally transferred from the study room to his supervision, and was prosecuted to an extent sufficient to show that whatever curious interest it might have, and however thoroughly the Service was justified in making these experimental researches, yet the observations were not likely, under existing circumstances, to be of value in the prediction of storms and weather.

Besides the elaborate final report of Prof. Mendenhall, which was published among the memoirs of the National Academy of Sciences, monthly reports were published for several years in the "Monthly Weather Review," and also numerous special articles by those engaged in the work. The improvements that were suggested by experience, and finally embodied in an improved form of the electrometer, may be regarded as a valuable outcome in view of any future work on this subject.

A special incentive to the study of atmospheric electricity was given by the report embodying the opinions of several physicians to the effect that the electric condition of the atmosphere influences human health, but this hypothesis is not yet substantiated by the experience of the Signal Service.

The subject of protection against lightning, and the collection of statistics relative to destruction by lightning, is a practical side of this subject that has been especially studied by Mr. McAdie.

Efforts were made, with some degree of success, to measure the earth currents at the international polar stations established by the Signal Service.

The aurora has been studied by the Signal Service, first of all in its chronological and geographical relations, in respect to which special memoirs were published by myself in the annual reports of 1872–'77, and in various monthly weather reviews. A larger collection of data on this subject is given in Gen. Greely's list of 1881. The relation of the aurora to the thunderstorms that appear simultaneously in the region surrounding that in which the aurora is exhibited was published by me in the "Monthly Weather Review" of 1874.

### *I.—Thunderstorms.*

The general relation of thunderstorms to areas of high and low pressure has always received special attention with a view to their possible prediction. The fact that they occur on the south and east sides of an area of low pressure was already known in 1871 from the maps that had been published in Europe and America, so that the general prediction, "conditions are favorable for severe local storms," was occasionally made even in that year. A map showing the general frequency of thunderstorms for the month of July, 1873, is given in the "Monthly Weather Review" for that date. The statistics gathered from the Smithsonian Institution and Signal Service records up to 1880 by Mr. Boehmer, as a private undertaking, were purchased, in manuscript, in 1882 as the first step in the proposed future investigations.

As the next step toward more detailed study and predictions the systematic collection of thunderstorm reports by postal cards from many observers within a small region was undertaken for the Signal Service by Prof. H. A. Hazen early in 1884. This work was continued by him for several years and, in connection with the work done by Profs. Davis, Upton, and Ward of the New England Meteorological Society, has prepared the way for the special study of thunderstorms by each of our State weather services. The prosperity of our crops depends very largely upon the local rains that fall in connection with these thunderstorms, and the harvesting of crops is greatly facilitated when such rains can be foreseen. As predictions will only become possible when the thunderstorm reports from many stations are telegraphed, perhaps twice a day, to a central office it is evident that the studies by the Signal Service must be still further prosecuted to a successful conclusion.

### *J.—Verification of predictions.*

Before beginning the publication of official weather predictions in February, 1871, I thought it best to make out detailed forecasts for each of the climatological sections into which I had divided the country. This was a sort of practice work that has ever since been required of those who are about to begin forecasting. The specific items predicted for each day were compared with the observed items as recorded on the weather map, and in October, 1871, I gave Gen. Myer a statement of the general accuracy of these detailed predictions as to one item only, viz, the wind; from this a published statement was made up which has generally been interpreted as claiming 69 per cent of complete verifications and 21 per cent of partial verifications for the published predictions, which, however, was not at all the case, as the published predictions were not verified in those days, and would, undoubtedly, have averaged much higher. The next step in

verifications was taken a year later, when Gen. Myer caused the published predictions, from October, 1871, to October, 1872, to be compared with the daily maps. This was done in continuous session by Maj. Dunwoody, and the result, as published in the Annual Report for 1872, was 76.8 per cent of verifications.

In October, 1873, a similar examination of the previous year's work was made, the resulting general average being 77.6. After this, however, it became evident that if the percentages were to be comparable among themselves from month to month and year to year, and especially if they are to be used in comparing the efficiency of the individual forecasters, then the four meteorological elements, wind, weather, pressure, and temperature, must be predicted invariably, and not merely when the predictor feels sure of the coming changes; moreover, the verifications must be made up by uniform stringent rules, in order to avoid the very large differences in personal judgments which, as a critical study had demonstrated, did actually exist. As any system of verification under these conditions will tend to stimulate the art of predicting for percentages rather than predicting for the public benefit, we must, therefore, avoid this tendency by some other rules. The rules hitherto devised, after frequent revisions, constitute a very important feature, and have a fundamental influence on the work of the Service. On the one hand, there has been brought about a uniformity in the style and nomenclature of the published forecasts, but, on the other hand, the terse terms and the technical meaning which the forecaster has in mind are oftentimes misunderstood and, therefore, misleading to the public.

As concerns the relative merits of the forecasters the percentages, as first deduced, convey no clear criterion; it, therefore, became the custom to combine the percentages of the five elements, pressure, temperature, wind, weather, and wind signals, into a single mean, giving a weight to each element in accordance with its importance to the public interest rather than in accordance with its meteorological importance; thus, the rain and weather received the greatest weight and the barometric pressure the least, or, in fact, of late years none at all. There are, however, still other considerations that must be combined with the percentages before we obtain a result that can be called a criterion of personal ability; the most prominent of these considerations is the fact that in some regions, and in certain months of the year, the meteorological conditions are so uniform that there can be no difficulty whatever in attaining a very high per cent without giving any special thought to the predictions; for example, the prediction of fair weather, or no rain, for California and Arizona during July, August, and September might be made every day without looking at the weather map and one would attain from 90 to 100 per cent of verifications. In fact, if the prediction of fair weather be made

every day throughout the year in any part of the country east of the Mississippi the author would receive 60 per cent of verifications, because we know that there are very few places that have more than a hundred rainy days in the year.

The difficulty of weather predictions and the importance of the predictions to the public consist equally in foreseeing both the changes and the times at which they will occur; therefore, the percentage of verifications still needs a factor depending on the variability of the climate. In some cases this fact is clearly recognized; for example, in the prediction of tornadoes one is not credited with perfection if he predict no tornadoes, day after day, even though this prediction is comforting, and, therefore, important to the public; he is only to be praised when he makes a successful prediction of the actual occurrence of the tornado. Another consideration is to be thought of when we have to deal with as small a matter as 1 or 2 per cent, namely, the thirty verifications of the daily predictions for a month for a given region and for a given element are each to be considered as either failures or successes, or else intermediate partial successes; if each is marked as either zero or 100, the average of the thirty will give a monthly mean whose intrinsic uncertainty is about 3 per cent, due to the fact that the thirty individual items oscillate to and fro from zero to 100, and the best judgment of the verifier will not enable him to preserve an even balance in his decisions as to whether a prediction is a success or a failure.

From 1873 until about 1890 an effort was made to diminish this latter difficulty by allowing a prediction to be considered as fulfilled to the extent of 0, 25, 50, 75, or 100 per cent. Subsequently, the areas of prediction and verification were very closely defined, and subdivisions, or steps of 10 per cent, were introduced, thus, eventually, this source of uncertainty has been largely done away with, excepting only the tendency of the verifier to make a judgment that is too severe or too lenient. The extremely small range of the percentages for the year 1872–'73, as compared with the range for the years 1888 to 1891, seems to show that the Signal Service system had maintained a high degree of accuracy and uniformity. In general, the tendency has been to officially judge the predictions more and more severely, so that the percentages claimed by the Signal Service were invariably less than those accorded by the estimates of the numerous local observers who have made monthly reports of the local verifications.

### *K.—Local forecasters.*

One of the matters most clearly foreseen, and, in fact, often urged by me upon Gen. Myer, was the propriety and the necessity of stationing experienced officers at such centers as Chicago, St. Louis, New Or-

leans, and San Francisco, for the purpose of making forecasts for those more remote sections of the country, as well as looking after the general interests of the people and the Service. A beginning of this kind was eventually made by establishing Lieut. Woodruff at St. Paul and Lieuts. Maxfield and Finley at San Francisco. But the original argument was to the effect that at every city where the map was published daily a local forecaster ought to be able to do better or, at least, as well as the Central Office in Washington, and that on many accounts it was best for the Service to develop a large board of forecasters rather than to confine the work to a few military officers in Washington. The force of this argument was finally felt, and the preparations for the work of the local forecasters was already being made by the Signal Service when transferred in 1891.

*L.—Diminution of temperature with altitude.*

The rate of diminution of temperature with altitude was studied in 1873 by Maj. Dunwoody, who made use of the observations on Mount Washington and Pikes Peak. In 1882, Prof. Upton and, in 1885, Prof. Ferrel made general determinations of this vertical gradient of temperature for the whole country in connection with methods of reduction to sea level; they combined all observations at high and low stations and, at the same time, included the variations with latitude and longitude. The special problem of the reduction of the barometer to sea level depends largely on the average temperature of the upper and lower air, and has been worked by the same gentlemen as also by Prof. Hazen. I consider that the Signal Service made a distinct advance in this matter, which is almost certain to be eventually followed by the rest of the world, in that it adopted Ferrel's reduction to sea level based on an approximate mean temperature of the air computed from all observations available within twenty-four hours, at the respective stations, rather than on the air temperature at the time of the reading of the barometer.

*M.—The visibility of signals.*

Many experiments have been made by the Signal Service as to the visibility of signals, and these relate quite as much to their adaptability as weather signals as to their use in military signaling. Lanterns and flags of many styles, shapes, and colors; the English drum, ball, and cone; the semaphore; the Ohio railroad system of colored disks; the steam whistle; the fire alarm bell, and other systems have been discussed and tested. The general result has been to confirm the Service in its use of the various styles of signal flags for display at telegraph stations and corresponding disks, plates, or devices for display on the sides of the cars of railroad trains. More recently the Orono system of three balls of different sizes on a vertical staff has also been considered.

*N.—Co-operation with others.*

As Gen. Myer considered the archives of the office the property of the Government for all to use freely, subject to certain conditions, he supplied any desired data, either in printed or manuscript form, to any applicant. The appendices to the annual volumes show how great a labor was thus sometimes imposed upon the office; one object thus attained was, that he secured voluntary laborers in the investigations of meteorology without increasing the number of civilian employees of the Signal Service. Most prominent among these was Prof. Elias Loomis, of Yale College, New Haven, who at very considerable personal expense conducted the measurements and computations, whose results are given in his "Contributions to Meteorology." Similar studies bearing on the meteorology of Alaska were carried out by Mr. W. H. Dall, of the Coast Survey. The temperature and rainfall data were freely furnished to Mr. C. A. Schott, of the Coast Survey, for his new edition of the "Smithsonian Temperature and Rainfall Tables," and a copy of his manuscript was preserved by the Signal Service. Equal facilities were given to many physicians and others for studies of the local climates and special atmospheric phenomena in their relation to diseases.

By arrangement with the Life-Saving Service of the Treasury Department the Signal Service maintained telegraph lines and in return received meteorological reports from their stations on the Atlantic seaboard and the Great Lakes. By arrangement with Prof. S. F. Baird, U. S. Fish Commissioner, the Signal Service observers for many years maintained observations of the temperature of the water in rivers and harbors. Monthly summaries were published in the "Weather Review." It was hoped that these observations would throw light on the migrations and habits of our principal food fishes. At the request of the trustees of the Dudley Observatory, Gen. Myer undertook to keep up the system of distribution of time from that center. In order to secure the magnetic and electric observations from reliable sources, Gen. Hazen co-operated with such universities as had facilities for this work. By an arrangement with the observatory of Harvard College, Gen. Greely secured the publication in full of the records from Pikes Peak, thus making them accessible to all meteorologists. The work done by Sergt. Frederick Meyer on the *Polaris*, that of Sergt. O. T. Sherman on the *Florence*, that of Prof. Upton on the U. S. S. *Hartford* and at the Caroline Islands, and my own on the U. S. S. *Pensacola*, the observations of the transit of Mercury in 1878, and those of the solar eclipse of 1878 illustrate the generous co-operation of the Signal Service with others.

*O.—Solar physics.*

On the occasion of the total solar eclipse of September, 1869, Gen.

Myer showed his appreciation of the subject by selecting the summit of Roan Mountain, N. C., as his station, and submitted his report as a voluntary observer for publication by the U. S. Naval Observatory. He was always interested in the intimate relation between solar physics and our atmosphere, and often spoke of the subject to me. At one time he hoped, by using the spectroscope to observe the sun when in the horizon, that he might determine some conditions of our atmosphere that would facilitate the prediction of rain and storm. An apparatus for this purpose, made by Lockyer, at the special request of Gen. Myer, was long kept in the instrument room. In 1871, the erection of a telescope to study the atmospheres of other planets was contemplated, and this thought was undoubtedly in Gen. Myer's mind, when, in 1873, he entered into an arrangement with the Dudley Observatory, undertaking to use the instruments of that institution for the benefit of meteorology. Although I could but dissuade him from this invasion of a cognate field of work, we were still glad to secure from Prof. D. P. Todd an excellent series of observations of the sun spots, which were for many years published in the "Monthly Weather Review." Gen. Myer was much gratified to be able to coöperate with the astronomers of the country in the observations of the transit of Mercury in May, 1878, and was equally pleased to find that many problems bearing on our atmosphere could be attacked in connection with an expedition to observe the total eclipse of the sun from the summit of Pikes Peak in July, 1878. A full account of that expedition is given in my appendix to the report for 1881, and Gen. Myer's personal interest in the matter is shown by the fact that, at the last moment, he journeyed rapidly from Washington to the summit of the Peak and was present to observe the phenomena. Some of the meteorological problems that were then formulated and attacked still remain to be solved.

*P.—Hourly observations.*

In order to make a contribution as great as practicable to the much desired system of hourly observations, the observers were originally instructed by Gen. Myer to make hourly readings of all available barometers and thermometers at each station during the last two days of each month. This was also supposed to serve as a partial check on any changes that might take place in the errors of the instruments. Observations of this character are at hand for most stations from 1870 to 1890, and in this way there has been accumulated the equivalent, as far as the mass of material is concerned, of one year's hourly observations of pressure and temperature at all stations. A large portion of this has not been utilized for diurnal periodicities, and the recent increasing use of self-registering apparatus may cause that earlier work to be superseded. For some time in

1881–'84 the Service, after abolishing the observations on local time at 7 a. m., 2 p. m., and 9 p. m., maintained a systematic record at 3 a. m., 7 a. m., 11 a. m., 3 p. m., 7 p. m., and 11 p. m. at nearly all stations, omitting only the 3 a. m. observation when the force of the station was inadequate. Such a series as this suffices for all ordinary climatological purposes.

*Q.—Publication of meteorological memoirs.*

In the early days of the Service no special provision was made for the publication of any meteorological investigations; in fact, as a general rule, independent publication was not encouraged by Gen. Myer, and although he announced that the publication of such papers had been provided for, yet during his administration we find that only a few special studies were officially published. In 1881, Gen. Hazen authorized the publication of a quarto series entitled "Professional Papers of the Signal Service," of which 17 were published, and an octavo series entitled "Signal Service Notes," of which 22 were published. Both these series were abolished in 1886 by a direct order from the Secretary of War, and the papers that were then on hand, intended for this mode of publication, were either printed as appendices to the annual report or allowed to be published elsewhere. To the uninitiated, the abolition of this series is somewhat of a mystery; it may, however, be explained that the special printing office maintained by the Signal Service, although necessary, was always an anomaly. There has long been a growing sentiment in Congress in favor of printing all government publications at the Government Printing Office, whereas the Secretaries of the various Departments have preferred to maintain for a certain class of executive work their own independent printing offices, and this was especially necessary in the matter of the publications of the Signal Service, whose maps, bulletins, and reviews needed close supervision and prompt publication by the experts of the office.

*R.—Bibliography.*

One of the most important efforts made by the Signal Service to contribute to the general progress of our science consisted in the "General Bibliography of Meteorology." The beginning of this was the acquisition of the general card catalogues of Mr. G. J. Symons, of London, and myself. The official work on the bibliography was inaugurated under Gen. Hazen's administration and was prosecuted by the study room, with the most generous co-operation on the part of the individual authors and of every government weather bureau in the world. Mr. C. J. Sawyer was engaged as civilian bibliographer. The catalogue was arranged on a system devised by Messrs. Sawyer and Lancaster and has been partially published, namely, the four sections on

temperature, moisture, winds, and storms, by Mr. O. L. Fassig, as Mr. Sawyer's successor, under Gen. Greely's administration. It is to be hoped that the whole of this great work, involving 65,000 titles, may be printed in uniform style, convenient for use, as it is sure to be wanted by every person studying meteorology and its applications.

A general bibliography of the publications written by members of the Signal Service is given by Mr. Fassig in the Annual Report of the Chief Signal Officer for 1891, from which we have occasionally extracted the titles quoted in this brief historical summary.

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## 5.—STATE WEATHER SERVICE ORGANIZATIONS.

Maj. H. H. C. Dunwoody, U. S. Army.

While the State Weather Service, as it exists to-day, is the result of the efforts exerted by the officials of the National Weather Bureau, a somewhat similar work, restricted to the taking and recording of meteorological observations, was undertaken much earlier than the existence of the National Weather Service itself, which was first provided for by Congress in 1870.

Before presenting some facts concerning the extensive and practical work of the State Weather Service, as carried on throughout the United States at the present time, it is of interest to refer to some of the early efforts to inaugurate systems of meteorological observations which form a prominent feature of State weather service work.

Attempts, by organized effort, to establish stations for the purpose of taking and recording meteorological observations were made as early as the first and second decades of this century by private individuals and State and Governmental officials, but active work in the lines upon which State weather services are operated to-day was not begun until 1881.

In 1825 the Regents of the University of New York directed that the academies under their jurisdiction should be furnished with thermometers and rain gauges for the purpose of taking and recording temperature and rainfall observations, which were begun in 1826 and continued, more or less completely, until 1850.

On the joint representation of the American Philosophical Society and the Franklin Institute, the Legislature of Pennsylvania, in the year 1837, voted an appropriation for the organization and conduct of a system of meteorological observations. Stations were established and equipped in each county of the State, and observers were obtained in various parts of the United States, and these observers, it is stated, corresponded faithfully with the two societies for a number of years, sending records of their observations, and more especially the details of storms.

In Massachusetts there was inaugurated, under State direction, in 1849, a system of meteorological observations which, in the following year, was merged with the national system undertaken by the Smithsonian Institution.

Prof. Gustavus Hinrichs, of Iowa City, Iowa, in 1875, began the work of securing observers in that State, and his continued efforts to perfect the organization of a State meteorological service were, in 1878, rewarded by the passage of a bill by the State Legislature of Iowa appropriating a sum of $1,000 per annum for the support of the Iowa Weather Service.

Shortly after the establishment of the Iowa service, a similar organization was effected in the State of Missouri, under the direction of Prof. Francis E. Nipher, of St. Louis.

The National Weather Service of the United States, after about ten years of existence, during which time its great practical value had been thoroughly demonstrated, and the National Congress had made generous provision for its needs, saw that, through the instrumentality of the local State weather services, there were possibilities for increasing the usefulness of the National Weather Service to an extent scarcely contemplated by its original founders, and during the early part of 1881 definite action was taken by the National Service looking to the establishment of auxiliary weather services throughout the country.

Gen. W. B. Hazen, U. S. Army, was appointed Chief Signal Officer during the latter part of 1880. Shortly after assuming charge of the Service he called upon his assistants to submit, in writing, suggestions for the improvement of the Weather Service, and the first definite action, looking to the establishment of State weather services as branches of the National Bureau, of which there is official record, is the suggestion by Lieut. Dunwoody submitted to the Chief Signal Officer, January 27, 1881. The following extract covers that portion of Lieut. Dunwoody's recommendation relative to State weather services:

* * * * * * *

Secure the favorable action of the State legislatures of the several States, requiring each county recorder to take observations of temperature, maximum and minimum, rainfall, and wind at stated hours, the same to be furnished to the Chief Signal Officer on postal cards printed at this office. This would not only enable this office to study the climatology of the whole country, but at the end of ten years would enable it to make very complete charts of rainfall and temperature for every section. This would not only increase the usefulness of the Service, as these reports could be collected weekly, but an auxiliary service could be organized in each State, under the direction of this office, which would tend to increase the importance of the Signal Service in every section of the country.

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In an official report, made in 1881, by a board of officers appointed

by the Chief Signal Officer to consider the suggestions submitted by his assistants, relative to improving the Service, the following appears:

The recommendation of Lieut. Dunwoody that State legislatures be requested to direct that certain observations be taken by the county recorders was then considered. Prof. Abbe suggested, as a substitute, that a letter be written to the governors of the States, except Iowa and Missouri (in which States local services then existed), inquiring what department of the State government, if any, was in charge of interests most nearly allied to meteorology, and whether such department could not co-operate with the Chief Signal Officer in advancing the interests of this Service by a system of observations throughout the State.

The proposition was favored by the Chief Signal Officer, who directed Lieut. Dunwoody and Prof. Abbe to draft such a letter, and submit it to him. This was done, and on April 11 the following letter and accompanying memorandum were sent to the governors of the several States and Territories:

SIR: By the organic law relating to the meteorological division of the Signal Service, a copy of which is inclosed, you will perceive that Congress contemplated therein a general weather service that shall be as useful as possible to the whole United States.

Experience has, however, shown that in many questions relating to agriculture and other interests, more minute details are needed, such as can only be obtained by having at least one report from every county, and this extension of the work must, for the present, devolve upon the individual States.

It is considered desirable that each State should, as far as practicable, establish some such system as is suggested in the accompanying memorandum.

I shall be pleased to learn from you whether there is any officer of your State authorized to assume charge of weather observations and climatic statistics, upon whom the duty of organizing such a work can be imposed by you, or whether special legislation will be required to enable you to establish a weather service in your State.

This office will always be glad to co-operate in the development of meteorological services in the respective States.

I am, very respectfully, your obedient servant,

(Signed) W. B. HAZEN,
*Brig. and Bvt. Maj. Gen.*,
*Chief Signal Officer, U. S. Army.*

MEMORANDUM.

The object of a State weather service should be to observe and utilize every feature of the weather that affects the prosperity of the inhabitants of the State as to crops, health, life, etc., omitting, perhaps, only those few items already provided for by the General Government at Washington, such as general storm predictions. The State service is, therefore, essentially a plan for gathering and utilizing local climatic data, and eventually it will define precisely the localities most favorable or unfavorable to special crops, diseases, etc.

The chief of the State service should be in such communication with the Chief Signal Officer of the Army that he may at any time receive from Washington and rapidly disseminate throughout his State any information of importance, such as predictions of frosts, tornadoes, floods, etc.

The State weather service may be wholly volunteer, and under the charge of a director or superintendent appointed by the governor, or it may be made a part of the duties of some officer now authorized by law, as the surveyor general, the superintendent

of public instruction, the president of some State college, scientific school, agricultural college, etc. The observer in each county may be a volunteer observer, or it may be made part of the duty of some county officer to make the daily record and monthly report.

Observations should be taken, if possible, at all State, county, and municipal offices and institutions, such as jails, asylums, hospitals, libraries, tollgates, colleges and high schools, waterworks, canal locks, etc.

The instruments used should, when practicable, be of uniform patterns, carefully tested by comparison with known standards before being used, and should include at least one maximum and minimum thermometer, one dew-point or other hygrometer, and rain gauge, all of which, with a supply of blanks and stamped envelopes for one year, need not cost more than $15 per station.

The director should be fully impressed with the importance of the work, and should issue each month a review, to be furnished to each county paper for publication and to each observer within ten days after the close of the month.

The Chief Signal Officer will be pleased to furnish sample forms, instructions for taking observations, price lists of standard instruments, and to give any information relative to this subject which the experience of the Signal Service may afford, and as an illustration of the action already taken by some of the States, a copy of the law establishing the weather service of the State of Iowa is herewith inclosed.

It was not expected that this letter would have the desired effect at once, for there were many obstacles and difficulties to surmount. Yet the answers received from the executive departments of the different States and Territories were gratifying and showed the interest manifested by the officials. Of twenty-four communications received in answer to the proposition, but one State, New York, looked upon a weather service as undesirable. The following is a true copy of the letter received from the governor of that State:

STATE OF NEW YORK, EXECUTIVE CHAMBER,
*Albany, February* 7, 1882.

SIR: The governor directs me to say, in reply to your letter of the 27th of January, that in his opinion the people of this State are not desirous of the establishment of a State weather service and, therefore, he is unable to comply with your suggestions.

Yours, respectfully,

HENRY E. ABELL,
*Private Secretary.*

Gen. W. B. HAZEN,
*Chief Signal Officer, U. S. Army, Washington, D. C.*

It may be here stated that New York which, at that time looked with disfavor upon the system proposed, has to-day one of the most thoroughly organized local services in the country, and the legislature has made repeated and liberal appropriations for its support.

The work of State weather services having thus been brought before the people of the several States, efforts, attended with success to a greater or less extent, were made in a number of States during the years 1881, 1882, and 1883, and by the close of the last named year, they were in successful operation in Indiana, Kansas, Iowa, Missouri, Nebraska, New Jersey, Ohio, and Tennessee. These were followed by the establishment of services in Alabama, Louisiana, Mississippi, and

New England during 1884. From 1885 to 1890 services were established in the Dakotas, California, Colorado, Georgia, the Carolinas, Arkansas, Pennsylvania, New York, Nevada, Texas, and Wisconsin; during 1891, in Arizona, Florida, Maryland, Montana, New Mexico, Virginia, Washington, West Virginia, and Wyoming, and 1892, in Idaho. At the present time the entire territory of the United States, except Alaska, is covered by State weather services.

For several years the gathering of climatological statistics and the dissemination of the weather forecasts and special warnings issued by the National Bureau constituted the principal features of State weather service work, but in 1887 the weather-crop feature was added, and this now constitutes the most valuable part of the work carried on. The first National Weather-Crop Bulletin was issued in Washington in May, 1887. It was received with much favor, and its appearance was soon followed by the issue of bulletins from the central stations of the State services. At the present time, local bulletins are issued in every State and Territory, with the exception of Nevada, where agricultural pursuits are not followed to an extent that would warrant the issue of such a publication. These weather-crop bulletins, both State and National, treat of the weather and crop conditions from week to week throughout the season of planting, cultivating, and harvesting of crops. They are based upon accurate and impartial information collected through the directors of the several local services from their special correspondents, of which there are about 6,000 in the United States. A telegram from each State center containing the more important features of the weather and crop conditions of the previous seven days is sent to Washington on Tuesday of each week for use in the National bulletin. All State telegrams are carefully considered at the Central Office in Washington in the preparation of the National bulletin, which is accompanied by two charts, showing, respectively, the temperature and rainfall conditions of the previous seven days. The publicity given the information contained in the State and National weather-crop bulletins is probably not exceeded by that of any other special class of information given the public through the press of the country. The circulation of the weather-crop bulletin thus attained can scarcely be estimated. The text of the National bulletin is telegraphed by the press associations, and is published in full by the principal daily newspapers throughout the country, and some of the most prominent agricultural journals, having circulations ranging from 100,000 to 500,000, besides printing the text of the bulletins, reproduce the charts illustrating the temperature and rainfall conditions. The editions of some of the State bulletins are very large, that of Ohio exceeding 11,000 copies weekly.

While the weather-crop service is now regarded as the most valuable

feature of State weather service work, scarcely less important is the work of collecting climatological data, the original object of the State service. Upon these data are based the monthly reviews issued by the several States, and upon which the National Service so largely depends for material upon which to prepare the "Monthly Weather Review" of the United States. Among the monthly reviews now issued by the local services may be found many publications possessing a high standard of excellence from scientific, literary, and typographical standpoints. The regular monthly reports now contain elaborate tables of meteorological data, and the several elements are generalized and discussed in a very thorough manner. In many reports the graphic illustrations of meteorological data are of a highly creditable character. With access to these monthly reviews of State weather services, it is possible to determine the special climatic features of any section of the country, and it would be difficult to estimate this feature of State service work, affording, as it does, a means of supplying to immigrants, invalids, and meteorological students detailed information which it would not be possible to secure were it not for the existence of the extensive system of meteorological observations conducted by State weather services.

Another valuable work of the State weather service is the dissemination of the weather forecasts and special warnings of severe storms, frosts, and cold waves. These forecasts and special warnings are telegraphed to distributing centers, whence they are distributed by telegraph, telephone, and mail to various points at which arrangements have been perfected for the display of flags or the sounding of whistle signals representing the forecasts. On July 1, 1893, there were nearly 3,000 stations in the United States receiving weather telegrams at the expense of the Government and displaying flags or sounding signals for the benefit of the public. Besides this, through other arrangements, a similar service is conducted at a like number of places without expense to the Government.

During the summer of 1892 an important work, viz, the investigation of thunderstorms, was undertaken in a number of States, with such satisfactory results as to encourage the prosecution of a similar work on a more extensive plan during the summer of 1893.

In conclusion, it must be said that the great success that has been attained by these State weather services is largely due to the cordial and substantial support which has been given by the present Chief of the Weather Bureau, Prof. Mark W. Harrington, whose appreciation of the value of these organizations co-operating with the National Bureau has prompted him to adopt a generous policy for the support and maintenance of these services where local and State aid could not be secured, the chief object being to render the work of the National Bureau of greater benefit to the people.

Too much praise can not be accorded to the voluntary observers, crop correspondents, and signal displaymen, whose services, given without compensation (save the benefits received in common with their communities), have made it possible to accomplish the work now being carried on. Without such voluntary assistance the State weather service could not exist.

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## 6.—EARLY INDIVIDUAL OBSERVERS IN THE UNITED STATES.

ALFRED J. HENRY.

In treating of the early individual observers in the United States, we shall refer briefly to the state of meteorological science at the time of the first permanent settlement, to the condition of the colonies during the early part of the eighteenth century, and finally to the methods and results of the earliest observers of which we have a record.

If we look for a beginning of interest in the phenomena of the weather we are soon lost among the shadowy forms of the earliest historic ages. At the dawn of history we find in the mythical tales of the early nations' descriptions of the phenomena of cloud, wind, and rain, often irrational and bordering on the grotesque, yet at times reflecting with some accuracy the climate of the country that gave them birth. At a later stage in the intellectual development of the race the results of observations on the weather took the form of proverbs and popular prognostics, some of which have survived and are current to this day.

Coming down to the early years of the seventeenth century we find that the essential instruments of meteorology had not been discovered; that popular interest in the prognostics was not sufficiently aroused to investigate the principles on which they were based or the cause of their failures; that no systematic observations of the weather had been made, if we except the crude work of the sailor and the shepherd; and that but little, if any, advance had been made during the long line of centuries that mark the era of speculation in all things pertaining to the weather. In short, it may be said that at the time of the colonization of America meteorology had no foothold among the physical sciences of the day. We find, however, that the value of a chronological record of events, allied somewhat closely to climatic phenomena, such as the closing of rivers by ice, the time of harvesting, etc., was appreciated as early as the fourteenth century.

The discovery of a new world having climatic characteristics half told or imperfectly understood, peopled by a strange race, and having many features of natural interest gave impetus to the faculty of observation, both as regards climate and other subjects.

Of the many notes on the climate of the new country that were doubtless made, only the barest fragments have been preserved. These we find in reports made by early travelers and explorers, in the early parochial and colonial records, in the letters and unpublished manuscripts of agents or others in the service of commercial companies, and in various other forms.

The earliest notes on the climate that we have been able to find, in a search that unfortunately can not be considered as an exhaustive one, are contemporaneous with the settlement of Jamestown, Va., in 1607. So good an authority as Dr. Noah Webster makes mention in one of his published works (1798) of the fact that the winter of 1607–'08 was extremely cold. Since this was the first winter season of the colonists in the new continent, however, there may be some doubt as to whether they were in a condition to withstand the rigors of even an ordinary winter and whether, as a matter of fact, the cold was unusually severe.

In this, as in all other historical references to the climate of the early period, the integrity of the record may be questioned on several grounds, chief among which is the fact that the evidence is almost invariably indirect and lacking in quantitive standards. It is but natural to suppose that in the present case the report of the cold of 1607–'08 was transmitted by word of mouth to each successive generation until finally it found permanent lodgment, nearly two hundred years later, in Dr. Webster's book. It should be remembered, also, that not until after the second war with Great Britain did the art of printing in the United States begin to flourish, and that the newspaper of the ante-revolutionary period, and even later, rarely contained any reference to the average weather conditions. The unusual or striking features were, however, duly announced, but the press at no time entered into serious competition with the "oldest inhabitant" in matters pertaining to the climate.

The weather between the first winter at Jamestown and 1631 seems to have escaped attention; the winter of 1631–'32, however, is on record as being unusually mild. Men were able to work in their shirt sleeves in the latitude of Philadelphia, Pa.

A few years later (1638) the Swedes founded a colony in the new world, and erected a fort near the site of the present city of Wilmington, Del. There came to this fort, on February 26, 1643, a few years before the invention of the barometer, a worthy Swedish clergyman, the Rev. Jno. Campanius. Campanius seems to have been impressed with the idea of making a permanent record of weather sequences experienced in the new world, for we find him engaged, soon after his arrival, in keeping a systematic account of the weather, day by day. This account he maintained throughout the years 1644–'45.

He set sail for his native country soon thereafter, and we would have been left in ignorance of his work had it not been for the efforts of his grandson, Thos. Campanius Holm: The latter compiled and published a short history of the Swedish colony, in a work entitled *Kort Beskrifning om Nya Sveriga*, Stockholm, 1702, in which he has given an abstract of the weather recorded by his grandfather. The following extract from January, 1644, illustrates the results achieved by Campanius, and is given as of interest in this connection:

January 1–10, cloudy and rainy weather, with occasional sunshine and somewhat warm; from the 10th to the 20th a pretty sharp cold, and there fell a good deal of snow; afterwards rain and thick fogs with sunshine at intervals, wind shifting from northwest to southeast and from southeast to south; from the 20th to the 31st it blew, at first, cold and hard, then came snow and sleet, now and then warm sunshine; gusts of wind from north, northeast, northwest, and south.

Campanius has, therefore, claim to being the first meteorological observer on the western continent.

Although the colony was captured by the Dutch a few years after the time of Campanius, a religious connection with the mother country was maintained for a number of years. The parochial records of the colony that have been preserved contain some of the earliest records of the weather that we have. Fortunately for the continuation of the meteorological notes begun by the Swedes, the great city of Philadelphia, with her far-reaching interests, was near at hand. The interruptions to navigation of the Delaware River by ice did not occur with the recurrence of the winter season, and it is, therefore, not surprising that maritime interests should keep diligent record of the severity of winter weather as it affected navigation. We have, consequently, references of more or less completeness to the character of every winter on the Delaware, from 1719 to date, in addition to the references between 1644 and 1719, thus furnishing one of the longest, if not the longest, chain of historical references in the United States.

The settlements of the French at Biloxi and Mobile, on the Gulf coast, and at New Orleans, in the early part of the eighteenth century, gave the needed opportunity for observing and recording the most striking climatic features of those regions.

The results of these observations have been collated and published in connected form by Maj. W. H. Gardner, of Mobile, Ala. Similar accounts for northern and eastern portions of the country have been prepared and published by various persons. The student of climatic changes has, therefore, at his disposal a series of historical references for the greater portion of the country east of the Mississippi, extending from the beginning of the eighteenth century to the present time. As before stated, these notes are generally lacking in comparable statements, yet they contain not a few facts of general inter-

est. Among the more prominent events mentioned are: The great snow in New England from February 19 to 24, 1717, when the snow lay five and six feet deep on the level all over New England; the severe winters of 1740–'41 and 1779–'80; the cold summers of 1812, 1816, etc.

The colonies grew apace, but no efforts appear to have been made to keep a record of weather changes from the time of Campanius to 1729, three quarters of a century. In Europe the condition of meteorological affairs was more encouraging. The discovery of the pressure and weight of the atmosphere at a time when they were not even suspected had a great influence upon the physical sciences.

The experiments conducted under the direction of Pascal induced the latter to institute a series of instrumental observations with a view to ascertaining the connection between the pressure of the air and weather changes. His brother-in-law, M. Perier, began to observe the barometer and thermometer at Clermont in 1649. Corresponding observations were said to have been made in Paris and Stockholm with the result that it was shown that the mercury rises in weather which is cold, cloudy, and damp and falls when the weather is hot and dry and during rain and snow, but with such irregularities that no general rule could be established. There were those, however, who confidently expected that changes in the weather could be anticipated by a knowledge of instrumental observations, but if we except the researches of Boyle, it may be said that no substantial progress was made from the observations of Pascal in 1649 to the time when the Royal Society of London, through its secretary, Dr. James Jurin, proposed a form for the taking of meteorological observations the world over (1723).

Approaching the instrumental period in the United States, let us look for a moment on the condition of the colonies as an influencing factor on meteorological work.

A fringe of the eastern coast, extending from Maine to South Carolina, was settled and in a fairly prosperous condition. The greater portion of the country was, however, a dense forest. The slopes from the hillsides to the edges of the rivers were but rarely broken by settlements. Here and there a hardy pioneer had hewn out an opening in the forest and built himself a rude cabin. He was menaced on the one hand by unseen foes and on the other by a struggle for the necessities of life under adverse circumstances. Such a scattered tenantry could give no thought to the taking of meteorological observations. In the cities, on the other hand, the conditions were scarcely more favorable. Instruments were both rare and expensive; the economic value of the observations was not understood; the co-operation of individuals in other cities was not assured; the means of interchange of observations were limited to stage coaches

and sailing vessels; scientific societies there were none; governmental aid and influence were unthought of. Whence, then, could come the means of gaining knowledge of the climatic features of the new continent? Clearly in but one way, viz, through the spontaneous action of men who so love the truth that in her pursuit they are willing to sacrifice personal affairs in order to win an insight into nature's laws. As before stated, the influence of the Royal Society in scientific affairs was paramount throughout the old world; it extended, moreover, to the western continent and touched the minds of the foremost investigators of the day.

The center of business activity in the colonies at this time, 1720 to 1730, was in Boston, the metropolis of New England, and a town of some 20,000 to 25,000 people. Among the foremost writers and thinkers of the day was the Hon. Paul Dudley, Chief Justice of Massachusetts, a close and intelligent observer of natural phenomena in the new world, and a member of the Royal Society of London. His interest in climatic research was doubtless due to his connection with that society, for we find him engaged in keeping a record of the weather three times a day, and the wind once or twice a day in 1729 and 1730. He communicated to a friend shortly afterward his purpose of procuring a barometer, but whether he did so or not is not now known. The results of his observations were communicated to the Royal Society, but have never been published.

Eight years later, at the extreme southern limit of the settled portion of the country, there was begun the first series of instrumental observations in the United States. This series possesses in a remarkable degree many of the refinements of later years. Dr. John Lining, the observer, was an eminent physician and an investigator of a high order of merit. Coming to Charleston about 1730, he entered upon the practice of medicine and continued an active practitioner upward of thirty years. The climatic conditions of Charleston were radically different from those of his native country, Scotland, and it is, therefore, not surprising that he should have been led to observe the weather with that degree of care and skill so characteristic of his professional work He began his observations in 1738, in connection with an elaborate series of statistical experiments upon himself. The causes which led him to undertake the observations are stated in a letter to the secretary of the Royal Society, under date of January 22, 1741, as follows:

I began these experiments on the first of last March and have continued them ever since with the loss of only a few days and propose to continue them until the year is finished. What first induced me to enter upon this course was that I might experimentally discover the influence of our different seasons upon the human body by which I might arrive at some certain knowledge of the cause of our epidemic diseases which regularly return at their stated seasons as a good clock strikes 12 when the sun is on the meridian.

The following description of the instruments used is not only of interest as showing the value of his observations, but also as indicating indirectly the state of the art of instrument making at that period:

The barometer is a common portable one, the diameter of its bore is about one-fifth of an inch. The thermometer is Fahrenheit's; the other thermometer is made by Theo. Heath in London, and is divided into 90 equal parts; 65 is the freezing point and 49 temperate. I suspect it to be the same as Hawksbee's, and have so called it in the tables. The hygroscope is a whip cord prepared after the same manner as that of the societies in Edinburg; the difference between its greatest and least length, by their manner of preparation, I found to be 5 inches, for which I made an index 5 inches long and divided it into 100 equal parts, the first of which is the hygroscope's greatest length.

These instruments are now placed on the outside of a northeast window in a large box about 3 feet broad, 6 feet high, and 1½ feet deep, which is so constructed that neither the sun nor rain can have access to the instruments, and it is at the same time sufficiently perforated to show the temperature of the air, having a great number of large holes regularly placed and passing obliquely upward in both sides and in the front with weather boards placed over each range of holes, so as to hang over them obliquely in the front, which is open from morning to bedtime. The shutters of the window are in many places perforated obliquely upward, that the air may have a free circulation through the box when the window is shut at night.

Unfortunately, no description of the rain gauge used has been left us.

Dr. Lining's hours of observation were "in the morning," "at 3 p. m.," and "at bedtime." His observations comprised readings of the barometer, thermometer, and hygrometer, noting the depth of rainfall and extent of cloudiness, and his record was maintained upward of eight years.

Dr. Chalmers succeeded Dr. Lining in 1750, and continued the work to 1759. From that year to 1790 no observations appear to have been made, but in 1791 a new series was begun, which was continued until 1810. The continuity of the record, from 1841 to the present time, if we except the period of the civil war, can be maintained by using the Fort Moultrie observations.

The observer succeeding Dr. Lining in point of time, was John Winthrop, LL. D., Hollis Professor of Mathematics and Natural Physics in Harvard College. The influence of this time honored institution upon the study and advancement of the physical sciences in the United States was felt almost contemporaneous with its establishment a century before the beginning of Dr. Winthrop's observations, but it is more especially in the astronomical field that Dr. Winthrop has cause to be remembered. His meteorological observations began in 1742 and continued upward of twenty years. The thermometric observations were made "morning" and "evening"; they give mean values somewhat lower than later observations, due, no doubt, to faulty exposure and the imperfections of the instruments of that period. The following description of the thermometer used by Dr.

Winthrop, from 1742 to 1759, is taken from his original manuscript in the possession of the American Academy of Arts and Sciences,[1] Boston, Mass:

> My thermometer was of Mr. Hawksbee's make, filled with spirit of wine. Ye scale is divided into 100 parts, beginning from a certain point above marked 0 and ye 100th degree falls just above ye bulb of ye thermometer. Ye freezing point is numbered 65°. Ye divisions are upward to 8° above zero. Ye observations are expressed in the degrees with their decimal parts. The instrument shows the highest temperature but not the lowest, for it goes into the bulb. How it was adjusted in London I know not, but it appears to me yt ye freezing point is marked considerably too high, for having plunged ye bulb into a vessel of snow I found yt ye spirit fell down to 76.5° and then rested.

From 1759 to 1763 observations were made with Fahrenheit's thermometer exposed on the north side of the house. Fortunately, comparative readings between the two thermometers were also made, so that it is possible to change the record by the Hawksbee thermometer to its equivalent in the Fahrenheit scale. The record begun by Dr. Winthrop was continued by others and has been maintained with more or less completeness to the present time. The number of years' observation at Cambridge and vicinity from 1742 to 1892 is 115 (for temperature).

The Philadelphia series of observations is the next in point of time to claim our attention. The first of these was made by John Bartram, at his botanic garden on the Schuylkill, using a thermometer graduated to the Celsius scale. He observed a little more than a year, beginning in 1748. Ten years afterward another series was begun, 1758–'59 and 1761–'77. The manuscript of these observations is in possession of the American Philosophical Society. Nothing is known of the details. From 1777 to 1825 a number of persons made observations for a greater or less time. In the latter year a series was begun at the Pennsylvania Hospital, Eighth and Spruce streets, and has been continued at the same place until the present time. The latter series, taken under uniform conditions throughout the whole period, is a very valuable one.

The fourth observer in the colonies in point of time is found in the person of Dr. Richard Brooke, who kept a thermometric record and a journal of the weather in Maryland during 1753 and 1754. While Dr. Brooke's record bears internal evidence of being carefully made, there are no details to be had as to the instruments he used nor even as to the precise point at which his observations were made. In the second year of his work observations were taken with considerable irregularity, and finally, in 1755, were discontinued altogether.

From the close of Dr. Brooke's record until 1760 no observations appear to have been made, except at Charleston, S. C., Cambridge,

[1] Investigations of the New England Meteorological Society, 1890, p. 116, by J. Warren Smith.

Mass., and Philadelphia, Pa.; at the latter place during 1758 and 1759 only. A year later (1760) Francis Fauquier, a friend of Jefferson, and Lieutenant Governor of Virginia, began a series of observations at Williamsburg, Va., the oldest incorporated town in the State, which he continued until 1762. Governor Fauquier used Fahrenheit's thermometer and observed at 8 a. m. and 2 p. m., except for a short time in January, 1760. Later Thomas Jefferson began a second series of observations at the same place in 1772–'77. We have also an account of meteorological observations that were made at William and Mary College, from July, 1777, to August, 1778. The observing hours for temperature were 8 a. m., 12 noon, and 4 p. m., in summer, and 8 a. m., 12 noon, and 3 p. m., in winter. The barometer was read and the direction of the wind and the state of the weather were observed at 8 a. m. only. Singularly enough, no observations in this city have been made since the work was discontinued by the illustrious observers above named, more than a century ago.

It would be wearisome to enumerate, in detail, the successive points at which observations were made during the latter half of the eighteenth century, suffice it to say that from 1760 to 1800, the following series were begun in the order named:

Bradford, Mass., 1772 to 1773, observations of barometer, thermometer, wind, weather, rainfall, and evaporation, by the Rev. Samuel Williams, A. M.

New Haven, Conn., 1778 to the present time, with a few interruptions. The observers were invariably connected with Yale College.

Ipswich, Mass., 1781–'82. Observations of temperature only. No details known.

New York, N. Y., 1782–'84. Two years' and two months' temperature observations are credited to De La Lerve, by Cotté. Later observers began in 1790 and continued for short periods; a continuous series, however, did not begin until the Medical Department of the Army took up the work at the forts in New York Harbor in 1820.

Salem, Mass., 1786–1828, by Dr. Edward A. Holyoke. Published in full by the American Academy of Arts and Sciences, Vol. I, new series, 1833. One of the most valuable of the early series. Dr. Holyoke's labors were continuous from 1786 to 1821; thereafter, his observations were made in a less regular manner, until the time of his death in 1829.

Nazareth, Pa., 1787–'92. No details.

Rutland, Vt., 1789. One year only. Williams' History of Vermont.

Fort Washington, Ohio, 1790–'91. Eleven months' observations.

Morrisville, Pa., 1790 to 1859, by Chas. Pierce, one of the earliest and best series made in Pennsylvania. No details.

Charlestown, Mass., 1792–1802. Rain only.

Albany, N. Y., 1795–'96. Observations of temperature by Simeon DeWitt.

Andover, Mass., 1798–1808. Temperature observations only.

Natchez, Miss., 1799–1803. Observations by W. Dunbar.

As the country grew in population, the number of observers slowly increased. The increase in 1806 was eleven, but that rate of increase was not maintained in the years immediately following.

Definite conclusions respecting the depth of rainfall, the average temperature, the amount of cloud, and the direction of the winds appear to have been reached by some as early as the beginning of the nineteenth century; on the other hand the theories in regard to the circulation of the winds and other problems of dynamic meteorology were exceedingly hazy. A writer referring to the southwestern winds, as late as 1803, says:

> A focus of suction then exists in the north of the continent, but it remains to be known whether this focus lies beyond or on this side of the Algonquin Chain, which skirts the lakes on the north. This can not be decided but by simultaneous observations on a line extending from the shore of Florida through Kentucky, lakes Erie, Huron, and the Algonquin Mountains to the borders of Hudson Bay.

It may be remarked, incidentally, that the idea of simultaneous observations, while developed within the memory of the present generation, is of more ancient date than is generally supposed.

The tornado, that much dreaded phenomenon of the interior, had been described more than a hundred years ago, although it remained for Loomis and the nineteenth century observers to investigate its terrible action.

The opinion that the climate was changing was held by not a few. Mr. S. Williams, the historian of Vermont, quoted a number of facts in support of this belief. Dr. Rush also advanced similar facts for Pennsylvania, and Mr. Thomas Jefferson likewise says:

> A change in our climate, however, is taking place. Both heats and colds are becoming much more moderate within the memory of the middle aged. Snows are less frequent and less deep.[1]

The epoch of individual efforts was nearing its close. The several series of observations thus far maintained were the outcome of private interest that often flagged in the absence of any stimulating force. There was, moreover, no central power to direct the efforts of the observers and to preserve the results of their observations. The original records were left in the hands of the observers, and thus, in many cases, became exposed to the vicissitudes that await written papers not filed as public documents.

The war of 1812 and the unsettled state of public affairs probably had much influence in keeping the interest in meteorological affairs

[1] Notes on Virginia.

at a low ebb; with the administration of Monroe, and the return of national prosperity, however, scientific work began to prosper.

Probably no more energetic and courageous believer in the possibilities of meteorology was to be found than Josiah Meigs, who, when Commissioner of the General Land Office in 1817, petitioned Congress to pass a resolution looking to the keeping of meteorological registers at the several land offices throughout the country. Congress failed to provide the necessary instruments or to have the observations taken under the sanction of public authority, but, nothing daunted, Meigs went ahead, and, with an inferior equipment, solicited the aid of the registers in the following letter:

CIRCULAR TO THE REGISTERS OF THE LAND OFFICES OF THE UNITED STATES.

GENERAL LAND OFFICE, *April* 29, 1817.

SIR: You will receive, with this, several blank forms of a meteorological register, to which I beg leave to request your attention.

The United States have already established 20 land offices, viz: At Detroit, Mich.; Wooster, Steubenville, Marietta, Zanesville, Chillicothe, and Cincinnati, Ohio; Jeffersonville and Vincennes, Ind.; Kaskaskia and Shawneetown, Ill.; St. Louis, Mo.; New Orleans, Opelousas, and north of Red River, in Louisiana; Washita and St. Stephens, in the territory acquired from the Creeks in the Mississippi Territory. These offices are dispersed over a space of about 18° of latitude and 10° of longitude.

The three columns for temperature, winds, and weather are ruled for 3 daily observations of each, viz, in the morning, at 2 p. m., and in the evening. The column entitled miscellaneous observations is intended to comprehend a variety of objects, among which are the following:

1. The time of the unfolding of the leaves of plants.
2. The time of flowering.
3. The migration of birds, whether from the north or south, particularly swallows.
4. The migration of fishes, whether from or to the ocean.
5. The hybernation of other animals, the time of their going in winter quarters, etc.
6. The phenomenon of unusual rains and inundations.
7. The phenomenon of unusually severe droughts. The history of locusts and other insects in unusual numbers.
8. Remarkable effects of lightning.
9. Snowstorms, hailstorms, hurricanes, and tornadoes; their course, extent, and duration.
10. All facts concerning earthquakes and other subterranean changes.
11. Concerning epidemic and epizootic distempers.
12. The fall of stones or other bodies from the atmosphere; meteors, their apparent velocity, etc.
13. Discoveries relative to the antiquity of the country.
14. Memorable facts as to the topography of the country.

A note as to notice of any or all of the above will be highly appreciated.

I wish you to transmit your observations monthly with your monthly official returns.

Whatever information may be thus obtained will be public property. My only object being the increase of our physical knowledge of the country. I flatter myself that you will not think my request unreasonable.

I have the honor to be, very respectfully,

(Signed) J. MEIGS.

The system inaugurated by Meigs fell far short of his original intentions. It consisted of observations of temperature, wind, and weather in the morning, at 2 p. m., and in the evening. Occasionally abstracts of the results of the observations appeared in the public prints, but no continuous records have been printed, nor is it definitely known what became of the orginals after the death of Meigs in August, 1822. That his collection was more comprehensive than is generally supposed may be inferred from the following extract from an article that appeared in "Niles Weekly Register," for 1819 (supplement to Vol. xv):

> The politeness of the registers of the land offices of the United States, and of several other gentlemen, has enabled me to collect meteorological facts and observations for nearly twenty years past. The places of observation extend from Detroit to Ouachita, New Orleans, and Savannah, including a space of 12° of longitude and latitude. The temperature by Fahrenheit's thermometer and the wind and weather are noted 3 times daily. If such observations are continued (as I hope they will be) for a few years, much interesting knowledge of our country will be obtained.

The published results of Meigs' system are confined to occasional statements of the monthly mean temperatures at a number of places, and also of the temperature of the coldest day. The fact that great cold is experienced almost simultaneously over considerable areas was first noticed by Meigs, but he apparently had no conception of the theory of the modern cold wave.

Of the several series of private observations, of which mention has been made, those of Charleston, S. C., Cambridge, Mass., Philadelphia, Pa., New Haven, Conn., and Salem and New Bedford, Mass., are, without doubt, the most valuable in the United States. The New Bedford series is particularly interesting and important, from the fact that it bridges in an unbroken span the eighty odd years that have elapsed since the original observer, the late Samuel Rodman, began to keep a record of temperature and rainfall in the little village of New Bedford, eighty-two years ago. Mr. Rodman's observations were carefully made, the best instruments attainable were used, and their position was changed but little during his lifetime. The sketch of his life, which follows, furnished by his son, Thomas R. Rodman, the present observer for New Bedford, is thought to be particularly appropriate at this time, drawing our attention, as it does, to the example of one who willingly gave of his time and money that the sum of our knowledge might increase:

> Samuel Rodman was born in Nantucket, Mass., on March 24, 1792. His father, also Samuel Rodman, was a native of Newport, R. I., the first habitat of the family in America. His mother was Elizabeth Rotch, born in Nantucket, and tracing her descent through Coffins, Starbucks, Macys, and other prominent Nantucket families, to the colonists of Salisbury, in the Massachusetts Bay colony.
>
> In 1798 he removed, with his father's family, to New Bedford, which was thereafter his residence. He died August 1, 1876.

He was by birth and conviction of the Society of Friends, and his ancestry, so far as it has been traced in every direction save one, was of that persuasion. His education was completed at a school in New Garden, Pa., under the principalship of Enoch Lewis, a mathematician of repute, and throughout life his tastes were for mathematics, mechanics, and science.

After leaving school he entered the counting room of his father, and presently engaged in business on his own account as merchant and manufacturer, wherein he was only moderately successful, being one of the few men who care not to accumulate wealth. All reforms had his sympathy, and pre-eminently he was an earnest, untiring, and consistent advocate of the cause of temperance and peace. He had few or none of the ordinary ambitions. To be useful and helpful in his generation to others, to hold himself to a strict accountability for the talents and time entrusted to him, so to live that his life might end at any time with no duty unperformed, were the motives and principles that influenced and guided him from early manhood to the end of his term of more than fourscore years. The line of Milton, slightly altered, which is inscribed on his tombstone at the suggestion of a beloved daughter who was soon to follow him, "Ever in his great Task-Master's eye," is a true epitome of his life and work.

Probably his studious tastes and interest in scientific matters, his locality and environment, directed him to meteorology. New Bedford, in 1812, when the weather record began, was a seaport with 6,000 inhabitants, an energetic people with alternating periods of great activity and great inaction. In the spring, summer, and autumn months, when the whaleships arrived, discharged their cargoes, and were again fitted for sea, there was great bustle and activity. With the departure of the last ship for the whaling grounds quiet settled upon the place. The mechanics' work was done, and the merchants had only the accounts to make of a business which for the time was closed. Communication with the outside world was by the Boston stage coach, which daily brought the mail. Outside of business matters was little intelligent interest, and life seems to have been, compared with that of these days, singularly barren and monotonous.

It seems most natural that in the dearth of matter for intelligent thought and occupation, in hours not required for business, a studious, conscientious youth, seeking employment for the moments that might otherwise have passed in idleness, should find that employment in a record of the phenomena of the weather, especially in a seaport town where old shipmasters, retired from the sea, were always, from force of habit, noting the atmospheric changes and prognosticating future conditions, often with wonderful accuracy.

The record begins August 11, 1812, and was kept continuously until September 17 following, when the sunrise observations were entered, and under "Remarks" the following: "Left home for Stafford Springs." A gap follows until October 3 following, when the record again commences to be kept without break until the present time.

The end crowns the work. "We build better than we know." When Samuel Rodman began his record, it is not too much to say that he believed he was doing work that would be useful to others. He could not foresee that his record of the rainfall would furnish the engineer with data wherewith he could safely make his estimates for the water supply of New Bedford. He could not foresee that his record of the humidity of the atmosphere would prove that in this regard New Bedford is as well fitted for the manufacture of cotton as Lancashire, England.. But the credit for these results belongs to him, as it does to those who patiently work, not with the knowledge of what their work may bring, but with the faith that labor brings its reward and to others than the laborers.

## 7.—SIMULTANEOUS METEOROLOGICAL OBSERVATIONS IN THE UNITED STATES DURING THE EIGHTEENTH CENTURY.

ALEXANDER McADIE, M. A.

Under the somewhat comprehensive caption "A notice of all that can increase the progress of human knowledge," the author of "Notes on the State of Virginia" "presumes it not improper nor unacceptable to furnish some data for estimating the climate of Virginia."[1] Virginia, it is perhaps necessary to recall, was not the Virginia of to-day, but a territory of some 120,000 square miles, 80,000 of which were westward of the Alleghanies. The "Notes" were written in 1781, somewhat corrected and enlarged in 1782, a few copies printed, a translation, somewhat mutilated, published in France, and the present form and language given to the world in 1787.

"Journals of observations on the quantity of rain and degree of heat, being lengthy, confused, and too minute to produce general and distinct ideas," this early American meteorologist continues, "I have taken five years' observations, to wit, from 1772 to 1777, made in Williamsburg and its neighborhood, have reduced them to an average for every month in the year, and stated those averages in the following table, adding an analytical view of the winds during the same period." Now comes the most remarkable step in these meteorological studies, viz, the making of simultaneous observations, or as Jefferson calls them, "contemporary" observations by himself at Monticello, and by Mr. Madison at Williamsburg.

By contemporary observations of between five and six weeks, the averaged and almost unvaried difference of the height of mercury in the barometer at those two places was .784 of an inch, the pressure at Monticello being so much the lightest, that is to say, about one thirty-seventh of its whole weight. It should be observed, however, that the hill of Monticello is of 500 feet perpendicular height above the river which washes its base.

And again:

The variation in the weight of our atmosphere as indicated by the barometer is not equal to 2 inches of mercury. During twelve months' observations at Williamsburg, the extremes were 29.00 and 30.86 inches, the difference being 1.86 of an inch; and in nine months, during which the height of the mercury was noted at Monticello, the extremes were 28.48 and 29.69 inches, the variation being 1.21 of an inch. Contemporary observations made at Monticello and Williamsburg proved the variations in the weight of air to be *simultaneous and corresponding in these two places.*

This is, I claim, the introduction of the principle of simultaneous observations in the United States.

But a more remarkable difference is in the winds which prevail in the different parts of the country. The following table exhibits a comparative view of the winds prevailing at Williamsburg and at Monticello. It is formed by reducing nine months' observa-

[1] Query 7, p. 104, edition of 1825.

tions at Monticello to four principal points, to wit, the northeast, southeast, southwest, and northwest; these points being perpendicular to, or parallel with, our coast, moun tains, and rivers; and by reducing in like manner an equal number of observations, to wit, 421 from the preceding table (given on p. 105 of the Notes) of winds at Williamsburg, taking them proportionably from every point:

| | NE. | SE. | SW. | NW. | Total. |
|---|---|---|---|---|---|
| Williamsburg | 127 | 61 | 132 | 101 | 421 |
| Monticello | 32 | 91 | 126 | 172 | 421 |

By this it may be seen that the southwest wind prevails equally at both places; that the northeast is next to this, the principal wind toward the seacoast, and the northwest wind is the predominant wind at the mountains.

Jefferson also comments upon the different sensations produced by the two winds. The distance between these two stations is about 120 miles, and for the sake of comparison I have taken the records at Norfolk and at Lynchburg, the distance being about 190 miles. The record at Norfolk is for seventeen years, 1872–'88, that at Lynchburg eighteen years, 1871–'88:

| | NE. | SE. | SW. | NW. |
|---|---|---|---|---|
| Norfolk | 3,192 **177** | 1,496 **108** | 3,382 **188** | 1,577 **88** |
| Lynchburg | 2,407 **142** | 793 **47** | 2,714 **159** | 2,342 **137** |

Comparing the figures in black we find Jefferson's deductions hold. The northwest wind is more frequent at Monticello and Lynchburg, or away from the coast and near the mountains, than at Williamsburg and Norfolk, coast stations, while the northeast wind is less frequent at Monticello and Lynchburg than at Williamsburg and Norfolk.

One other interesting feature of Jefferson's meteorological work, which can be only very briefly alluded to here, is found under his remarks on frost. We know the phenomenon to-day under the name "inversion of temperature." Jefferson writes:

The access of frost in autumn and its recess in spring do not seem to depend merely on the degree of cold, much less on the air being at the freezing point. White frosts are frequent when the thermometer is at 47°, have killed young plants of Indian corn at 48°, and have been known at 54°. Black frost and even ice have been produced at 38.5°, which is 6.5° above the freezing point. That other circumstances must be combined with the cold to produce frost is evident from this also, on the higher parts of mountains where it is absolutely colder than in the plains on which they stand, frosts do not appear so early by a considerable space of time in autumn and go off sooner in spring than in the plains. I have known frosts so severe as to kill the hickory trees around Monticello and yet not injure the tender fruit blossoms then in bloom on the top and higher parts of the mountain, and in the course of forty years during which it had been settled there have been but two instances of a general loss of fruit on it, while in the circumjacent country, the fruit has escaped but twice in the last seven years.

## 8.—THE REDFIELD AND ESPY PERIOD.[1]

Prof. William Morris Davis.

The direction of the advance of meteorology in this country during the period of twenty-five years, from 1830 to 1855, was so distinctly determined by the investigations of the two leaders, Redfield and Espy, that the meteorological history of that time is clearly portrayed by the account of their individual efforts. Their followers gave them able support, and certain independent students contributed valuable chapters to the science; but as a period in the history of the subject in the United States, the time was distinctly characterized by what Espy and Redfield thought and said.

We may give a moment to considering briefly the status of the science at the opening of the Redfield-Espy period. Then, as now, most persons interested in meteorology were simply observers of the weather whose records truly served for the determination of climatic data, without which progress would have been slow, but whose thoughts seldom carried them into persevering inquiries concerning the nature and explanation of the phenomena that they observed. There were no general isothermal charts; isobaric and rainfall charts of the world did not appear for many years later. Charts of the winds had hardly been improved over the sketch of the trade winds made by Dampier over a century before. The nature of storms and their relations to the general movements of the atmosphere had hardly been perceived. It is true that Franklin had detected their progressive motion, and that Mitchell had labored earnestly to solve their processes; that Capper, in India, had briefly stated his belief that the storms of that region were great whirlwinds, and this in much more definite language than that in which Langford had given the same name to the storms of the West Indies at the close of the seventeenth century; it is true that Brandes had approached the same idea in Europe, and that Dové[2] had fully reached it before the close of the third decade of this century. But all these suggestions and discoveries were unknown, as far as we can make out, to meteorologists in this country. Storms were thought to be straight-line gales. Looking at the difference between these modern days, when atmospheric processes have been so fully determined and clearly explained, and

[1] The original scheme of Section IV provided for a paper on "The Contributions to Theoretical Meteorology in the United States prior to 1830." Having failed to secure a writer for this paper, the chairman begs to refer to a valuable historical article in the Journal of the Franklin Institute for February, 1889, on "Some American Contributions to Meteorology," in which Prof. Davis fully presents the contributions of Benjamin Franklin, the principal actor of this early period.—Editor.

[2] The writer is aware that the use of an accent in Dové's name is incorrect, but he prefers to suffer the slight burden of this error rather than have the great German meteorologist spoken of as if he were the bearer of an olive branch.

those older times when so little had been discovered, it reminds one of the difference between a bright clear sky and a dull pall of clouds.

A break in these clouds over our horizon was made in 1831 when Redfield published his first essay. He then not only correlated and explained the observations that he had gathered concerning a few of our more severe storms; he extended his statements to the definite announcement of generalizations of great novelty and wide application. He said that not only our severe equinoctial hurricanes, but all storms are great revolving whirlwinds, turning from right to left, and gradually progressing northeastward; that the winds increase in violence toward the center of the whirl, but at the center there is commonly a calm; that the storms are regarded as gyrating portions of the atmosphere in which they are carried along; and that the low barometric pressure at their center is due to the centrifugal force of their whirling winds. Moreover, the great practical value of these conclusions in giving means of determining the bearing and probable course of the dangerous part of the storm was clearly perceived. The omission of all reference to any centripetal acceleration, the reference of the West India storms to eddies in the trade winds caused by islands or by conflicting winds, and the explanation of the storm clouds and rain by the "depression of the cold stratum of the upper atmosphere" are the chief deficiences in this remarkable paper. We can not help regretting that Redfield did not in his first essay use such a word as vortex, instead of whirl, for it appears from his later essays that he had the idea of a vortex in his mind. But far above these deficiencies stand the correct statements which mark the high value of this first publication of our great meteorologist. There is little wonder that it attracted much attention among men of science.

It is impossible here to follow through an abstract of all Redfield's numerous papers. I shall simply select certain of his statements, chiefly concerning cyclonic storms, which indicate the definite progress that he made toward what we now believe to be established facts, and the clearness of language in which he announced his beliefs. In 1834 he reached the fine generalization that—

> There is reason to believe that the great circuits of the wind, of which the trade winds form an integral part, are nearly uniform in all the great oceanic basins; and that the course of these circuits and of the stormy gyrations which they contain is, in the southern hemisphere, in a counter-direction to those north of the equator.[1]

In 1843 Redfield made explicit mention of the law of the conservation of areas in accounting for the greater velocity of the wind near the center of the tornado (Amer. Journ. Science, XLIII, p. 272), and in 1846 he refers to the same law to explain the greatly accelerated velocity of rotation in the wind on nearing the axis of a great hurricane (Hurricanes and Northers, New Haven, 1846, p. 87, or Amer. Journ. Science, II, 1846, p. 179).

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[1] Amer. Journ. Science, XXV, 1834, p. 121.

Already, in 1834, he had ascribed "the ordinary routine of the winds and weather" in the temperate latitudes to the passage of rotary storms, and the irregular variations of the barometer are referred to as "the larger atmospheric eddies" (Amer. Journ. Science, xxv, pp. 120, 129). Many years were needed to teach this simple lesson. It was never generally learned until the publication of daily weather maps, yet Redfield seems to have had the idea constantly in mind. In 1846 the great variations of temperature in winter weather are shown to result from the passage of rotary storms, with warm southerly winds in their front and cold northerly winds in their rear (Hurricanes and Northers, p. 102). This was an early step in our understanding of cold waves.

In all his writings Redfield seems to have had a thoroughly rational view of the general classification of the stormy disturbances in the general circulation of the atmosphere; and in one of his latest publications he wrote as follows, under the heading "What are cyclones?":

> The term cyclone was first proposed by Mr. Piddington to designate any considerable extent or area of wind which exhibits a turning or revolving motion, without regard to its varying velocity or to the different names which are often applied to such winds. * * * Thus, all hurricanes or violent storms may, perhaps, be considered as cyclones or revolving winds. But it by no means follows that all cyclones are either hurricanes, gales, or storms. The word is not designed to express the degree of activity or force which may be manifested in the moving disk or stratum of rotating atmosphere to which it is applied. It often designates light and feeble winds, as well as those which are strong and violent. * * * The more inert and passive cyclones, which seldom gain attention, but which constantly occupy in their transit the greater portion of the earth's surface, appear to move in orbits or courses corresponding with those of the more active class which have been traced on storm charts. * * * In a broad view of the case, the constant occurrence and progression of the cyclones in various degrees of activity constitute the normal condition of the inferior or wind stratum of the atmosphere, at least in the regions exterior to the trade winds of the globe.[1]

This has always seemed to me a truly sagacious paragraph. It is a serious regret that the terminology here advocated has not been generally adopted, and that the unwarranted extension of the term cyclone to designate tornadoes in later years has not been avoided. As if still uncertain what name to give those traveling areas of low pressure on which our weather changes depend, they are now often called storms, even in the official weather predictions, although there may be nothing stormy in their mild activity.

Redfield's generalizations were overlooked or disputed by many European writers, who, under the leadership and authority of Dové, looked to the general circulation of the atmosphere, rather than to subordinate disturbances within the general circulation, for the cause of weather changes. Indeed, Dové, after making a brilliant begin-

[1] Amer. Journ. Science, XVIII, 1854, pp. 188–189.

ning in advance of Redfield in the study of cyclonic storms, failed in later years to keep pace with him. Even after the publication of weather maps in 1860, Dové was inclined to doubt or even to dispute the truth of the generalizations which Redfield had announced so clearly before any weather maps were published to give daily evidence of the correctness of his views.

When Redfield first began his studies, he said simply that storms were rotary winds, without defining precisely what he meant by that rather general term. The natural meaning of it is that the winds run around the storm center in circles. Partly from his own studies, and as we may presume, partly by reason of the discussions aroused by Espy's theories, Redfield soon made a more precise statement of his meaning. After his first essay in 1831, in which both text and diagram implied circular winds, a chart, dated 1835 and published in 1837, contains diagrams which represented the spiral course of the winds, about as now generally understood; but the text still implied only horizontal circuits around the center. Two years later Redfield wrote:

> In the most violent of these storms, it is at least probable, if not certain, that the course of the surface wind is spirally inward, approximating gradually toward the center of the storm.[1]

Finally, in 1846, we meet the often quoted passage concerning Redfield's original understanding of the vorticular quality of cyclonic storms:

> When, in 1830, I first attempted to establish by direct evidence the rotative character of gales or tempests, I had only to encounter the then prevailing idea of a general rectilinear movement in these winds. Hence, I have deemed it sufficient to describe the rotation in general terms, not doubting that on different sides of a rotary storm, might be found any course of wind from the rotative to the rectilinear. But I have never been able to conceive that the wind in violent storms moves only in circles. On the contrary, a vortical movement approaching to that which may be seen in all lesser vortices, aërial or aqueous, appears to be an essential element of their violent and long continued action, of their increased energy toward the center or axis, and of the accompanying rain. In conformity with this view, the storm figure on my chart of the storm of 1830 was directed to be engraved in spiral or involute lines, but this point was yielded for the convenience of the engraver. The common idea of rotation in circles, however, is sufficiently correct for practical purposes and for the construction of diagrams, whether for the use of mariners or for determining between a general rectilinear wind on the one hand or the lately alleged centripetal winds on the other. The degree of vorticular inclination in violent storms must be subject locally to great variations; but it is not probable that on an average of the different sides, it ever comes near to 45° from the tangent to a circle, and that such average inclination ever exceeds two points of the compass, may be well doubted.[2]

This is so clear a statement, and comes so near to what is now generally understood to be the truth that it is curious to note how slowly

[1] Amer. Jour. Science, xxxv, 1839, p. 204.

[2] Hurricanes and Northers, 1846, p. 16.

the importance of the fact of incurvature of hurricane winds has been received among mariners. Until a few years ago the circular storm diagram was published even on our U. S. Hydrographic Pilot Charts of the North Atlantic. It is probable that Meldrum, of Mauritius, has had greater influence than any one else in securing the adoption of the modified law of storms by navigators, as dependent on an incurved path for the winds; and this because of his repeated accounts of incurvature in the storms of the southern Indian Ocean, and because of the publication of his reports by the English Meteorological Office, through which they naturally had a wide distribution.

Redfield's activity in gathering data and his perseverance in discussing the results were so great that we still find charts of storm tracks published as standards, in which there is little added to his charts of forty years or more ago; and such additions as are made come chiefly from his contemporary and sympathetic co-worker, Col. Reid, Governor of Barbadoes. We might not unreasonably include an account of Reid's work here, for although done by an Englishman, it was done on the American side of the ocean, and nearly all of the storms studied were American storms. But there are other students of our own to whom we must shortly turn.

It is curious, in reviewing Redfield's writings, to see how cautious he was as regards the suggestion of explanations for the phenomena that he described so well. In studying tornadoes, to which he gave some attention as well as to cyclones, he was occupied chiefly with the accurate determination of facts; whatever he thought as to causes he wrote little about them. One of his most definite approaches toward theoretical explanation is seen in the following extract:

> In most gales of wind there is probably a subordinate motion, inclining gradually downward and inward in the circumjacent air, and in the lower portions of the gale; and a like degree of motion, spirally upward and outward in the central and higher portions of the storm. This slight vorticular movement is believed to contribute largely to the clouds and rain which usually accompany a storm or gale, and is probably due, in part, to the excess of external atmospheric pressure on the outward portion of the revolving storm.[1]

Noting briefly that this is a singular forecast of the present view of the external, non-spontaneous cause of cyclonic action, we must point out that here enters in Redfield's writings a distinct indication of the influence of his contemporary, Espy, to whose remarkable genius we must now give attention.

In contrast to Redfield, Espy was continually theorizing. He did not neglect to observe at the same time, but he immediately desired to compare the facts determined by observation with the consequences deduced from reasonable physical processes of explanation. His style was positive and aggressive. "I do not submit to authority,"

[1] Trans. Amer. Phil. Soc., VIII, 1843, p. 79.

he said. His writing is much more disputatious than Redfield's. While he of course made mistakes, his insight into certain meteorological processes, that had before his time received little attention, was extraordinarily clear. Many of his contributions to the science still hold a high place. Some of them have even been independently rediscovered, and have given high credit to their new advocates after Espy's share in their original announcement had been forgotten.

The most important general principle that guided Espy's work was what is now called the adiabatic change of temperature in ascending or descending currents of air, and the effect of the condensation of vapor or the evaporation of clouds on the rate of this change. There seems to have been practically no attention paid by meteorologists to this all-important matter until Espy took it up and advocated it with all his ardor. It has since been much more accurately defined, but without introducing significant departures from Espy's conclusions. The general process of convection had, of course, long before been recognized as applicable to the movements of the atmosphere, and the change of temperature accompanying the expansion and compression of gases was well known, but curiously enough, the cooling of ascending currents on account of their expansion and the warming of descending currents on account of their compression had not been perceived as an essential part of the process. Hutton's impracticable theory for the production of cloud and rain by the mixture of two masses of saturated air at different temperatures had no rival until Espy introduced its proper successor.

With this principle continually in mind, Espy strove to discover the meaning of the atmospheric processes that are always going on around us. He was, therefore, not a climatologist but distinctly a meteorologist. This is most distinctly shown in the synopsis at the beginning of his "Philosophy of Storms," published in 1841, and which he recommends to his readers as containing the essence of his theories. It was prepared for presentation to the British Association the year before.

Many a modern observer of the weather might profit from this remarkable essay. It is presumably to these pages and to his later reports that Dr. Hann, of Vienna, the leading European meteorologist of to-day, refers in the following words:

When, several years ago (1881), I first * * * read Espy's works over more carefully, I saw, to my astonishment, that this eminent meteorologist, who has never been appreciated in proportion to his services, had announced a great number of those principles which we are accustomed to consider as the acquisitions of the so-called modern meteorology, and this not as casual suggestions, which under scientific criticism have hardly any value, but as the results of correct physical theory, tested by observations.[1]

The simple course of the regular diurnal phenomena of the weather

[1] *Meteorol. Zeitschrift*, Berlin, II, 1885, p. 393.

received explanation in this synopsis in a manner that shows how the most commonplace facts are illuminated by intellectual genius:

When up-moving currents are formed by superior heat, clouds will more frequently begin to form in the morning, increase in number as the heat increases, and cease altogether in the evening, when the surface of the earth becomes cold by radiation. The commencement of the up-moving columns in the morning will be attended with an increase of wind, and its force will increase with the increasing columns, both keeping pace with the increasing temperature. This increase of wind is produced partly by the rush of air on all sides at the surface of the earth toward the center of the ascending columns, producing fitful breezes, and partly by the depression of the air all around the ascending columns, bringing down with it the motion which it has above, which is known to be greater than that which the air has in contact with the asperities of the earth's surface.[1]

This is the original explanation of the diurnal increase of the wind's velocity, which has since been rediscovered independently by Köppen.

On another page he writes as follows regarding the retardation of cooling of ascending cloudy currents:

As soon as cloud begins to form, the caloric of elasticity of the vapor or steam is given out into the air in contact with the little particles of water formed by the condensation of the vapor. This will prevent the air, in its further progress upward, from cooling so fast as it did up to that point. * * * It follows that when the cloud is of great perpendicular height above its base its top must be warmer than the atmosphere at that height, and consequently much lighter.[2]

It was to this assistance of the ordinary convectional process that Espy appealed for the motive force of storms. He was certainly right in claiming much for this theory. It is indispensable in all modern discussions of the science. It may be added that very few modern text-books present the case more clearly than Espy did in his synopsis, except that his old fashioned terminology is, of course, now changed for one more in accord with the mechanical theory of heat.

An essential corollary of Espy's theory, fully recognized in his writings, was that descending currents would be warmed by compression at the same rate that ascending currents are cooled by expansion, and that after descending from a considerable height, they would be not only warm but dry also. It was on Espy's presentation of this subject in Paris that a çommittee of the French Academy (Arago, Pouillet, and Babinet) reported in 1841: "We should not, hereafter, adduce in the mean state of the atmosphere a descending current as a cause of cold." However cold the air may be aloft, it will be warmed by compression in descent, and hence will reach the surface of the earth with a high temperature. It was for this reason that Espy objected to the suggested origin of thunder-

[1] Philosophy of Storms, p. xiv.
[2] Philosophy of Storms, p. x.

storms by the descent of cold air from above into the warmer air below. Similarly, Espy explained the rainy belt around the equator, not by saying, as is still so common and so incorrect, that the warm, moist, and light surface air rises into the colder strata of the upper atmosphere, thus implying that the lower air is cooled by the cold of the upper air, but by saying that the warm, light air cools as it rises, and so condenses its vapor spontaneously. In the same way, winds that are constrained to rise as they flow over mountain ranges become cloudy and give forth rain, not because they are cooled by the cold of the high mountains, but because they are cooled in consequence of expanding during ascent. A good many modern writings are less accurate than this.

There are three other subjects of interest to which Espy gave some attention, and to which, at least, a paragraph should be given here He came apparently by deductive methods to a good understanding of the adiabatic processes governing the warmth and dryness of fœhn winds as early as 1841; and in his "Fourth Meteorological Report" (1857), he gave a remarkably clear account of such winds, instancing several examples in different parts of the world. In the same report, he suggested in an incidental way that the most probable cause for the clearness of the eye of a tropical cyclone was to be found in the descent of upper air within the ascending vortex of the storm; a suggestion since revived as the most effective cause of this curious phenomenon. Again, in his "Fourth Report," he approached but did not quite reach the meaning of the prevailing low pressures of the polar regions. He suggested that it might be the result of the rotation of the atmosphere with the earth; but he failed to notice that it is the rotation of the circumpolar currents at a faster rate than the earth's rotation that causes the polar barometric depression. I mention these points not as chief accomplishments in Espy's work, but to illustrate the activity of his mind, and the generally correct views that he had of meteorological processes.

Like Redfield, Espy found his chief subject for study in the larger atmospheric storms. Unfortunately, he seems to have approached this subject with a strong prepossession in favor of convectional indrafts, to which he was led by his theory; and in spite of evidence that now seems, on reading it over, distinctly against him, he could see no virtue in the conclusion that storm winds were essentially vorticular whirlwinds on a large scale. Espy received aid first from the Franklin Institute in Philadelphia, and afterward from the National Government, to which he was appointed Meteorologist. But even with a great array of facts before him he could not perceive the essential quality of the whirlwind. To him a cyclonic storm was a system of inflowing winds, not necessarily radial, but directed obliquely toward a north and south axis of low pressure; the low pressure at

the storm axis or center was the result of higher temperature and less density of the cloudy air of that region, and hence acted as the cause of the inflowing winds. Espy saw no virtue in Redfield's belief that the centrifugal force of the whirling winds caused the low central pressure; and naturally enough he could perceive no force in Herschel's objection that if the winds flowed on centripetal courses there should be high pressure at the center. In some of his later writings he admitted that there might be a slight whirling at the center of tornadoes, but he attached little importance to such movements, and in the larger storms he hardly recognized them. It is certainly curious that with such diagrams as he prepared himself for the storm of December, 1839, and as he copied from Piddington for storms in the Bay of Bengal, he could not recognize the essentially rotary quality of the winds.

Our two great meteorologists never agreed on the character of the storms which they both studied so closely. They and their ardent followers, Bache, Hare, Henry, Johnson, Olmsted, and others, wrote many disputatious articles, sometimes in too polemical a style, each maintaining the truth of his own party and attempting to disprove the position of his opponents. We can only regret the strength of feeling shown at that time, and wish that each had endeavored to see the truths, rather than the errors, in the contribution of the others.

I can not help feeling that if Espy, in particular, had shown more appreciation of a certain remarkable article, "On the rotary action of storms," that was printed in the "American Journal of Science" for 1843, at the very height of the discussion, he might have profited greatly by its suggestions, and have perceived that the views of both parties were right in a measure, and wrong in denying true elements in the views of the other. Charles Tracy, then a young graduate of Yale College, with a taste for mathematics, said to himself—if we may reconstruct his mental revery—Redfield and Espy are both right. Espy is right in maintaining that the tendency in storms is centripetal, for the primary cause of the movement is low pressure about the center of the storm; and Redfield is right in insisting that the storm winds have an essentially whirling movement, because the rotation of the earth will inevitably cause such a whirling in any system of centripetal winds. In Tracy's simple article, the deflective effect of the earth's rotation was for the first time properly applied in meteorology. The effect of the earth's rotation on the course of the winds had been noted by Hadley in 1735; but Hadley's explanation, still frequently quoted, was wrong in implying that the earth's rotation affects only meridional motions (or meridional components of motion), and that it directly alters the velocity of motion. Tracy, following apparently without knowing it in the path of certain mathematicians, stated the problem correctly, and was the first to

apply its results correctly to the case of the winds. It is remarkable that Espy was not moved by this essay, for we can hardly suppose that he did not see it. His own arguments proceeded, as Tracy's did, almost entirely in a deductive manner. He should have sympathized with Tracy's method of presentation; but I have searched his writings in vain to find the least sign of recognition of the general principle of the deflective force arising from the earth's rotation.

Tracy perceived that if an original impulse were the cause of the rotary movement of a storm, "the forces of the whirlwind would be rapidly exhausted and its existence must speedily cease. A stable source of momentum, adapted to originate and sustain the rotary movement, is still required, and it is proposed to develop such a source of momentum in the forces generated by the earth's diurnal rotation." It was admitted that Espy had established "a qualified central tendency of the air in both the general storms and the smaller tornadoes," and then, acting on this beginning, the deflective force arising from the earth's rotation is called on "to cause and maintain a whirlwind. * * * Upon the same principle, the typhoon and the wide-spread storm of the Atlantic, if their currents move toward a central spot, must have a rotary character. In every such case the incoming air must be regarded as a succession of rings taken off the surrounding atmosphere and moving slowly at first but swifter as they proceed toward the center. Each such ring is affected by the law of deviation during its passage, * * * and hence the ring begins to revolve when far from the center, turns more and more as it draws near it, and finally as it gathers about the central spot all its forces are resolved into a simple whirl. * * * In the Southern Hemisphere the same law of deflection produces contrary results." It is clearly shown that the deflective force is independent of the direction of motion, but varies with the sine of the latitude. "The necessary condition, centripetal motion, may arise whenever a central spot subjected to intense heat is surrounded by a cool atmosphere. * * * The destructive storms of our seacoast may have such an origin among the eastern islands of the West Indies, from which they appear to proceed."

There are few scientific essays of equal brevity that outrank this one of Tracy's for clearnesss and pertinence of statement at a critical time in the growth of a science. Yet, for forty years the essay was never mentioned, as far as I can learn; its forcible explanation seems to have made no converts. Like Hadley's original explanation of the oblique course of the trade winds, Tracy's essay stood alone as his single contribution to meteorology. Like Hadley's contribution, Tracy's lay neglected until his theorem had been developed and applied by others. But while Hadley always receives a due share of credit in the history of the science, Tracy's name is seldom mentioned.

I think the two should go together as equally deserving of renown. Early in 1883 I had the pleasure of meeting Mr. Tracy, just after having, as it were, resurrected his essay of forty years before. He said he had often wondered why attention had not been given to it, adding quietly "I have never been able to see that it was incorrect." It is to be regretted that so original and so acute a mind was diverted entirely from a study in which we must think it would have labored to great advantage. Mr. Tracy adopted the profession of law and attained a high position in that calling in the city of New York.

The labors of Loomis and Coffin began during the Redfield-Espy period, and continued into later years, where their more mature results should be considered. I wish, however, to give brief extracts from certain of their writings, touching the subject of storms, which was then the leading problem of meteorology; for although Coffin labored chiefly on the general winds of the globe, that important topic did not attain prominence until it was correctly treated by Ferrel, whose first essay comes at a later date than any that I shall consider. The great collection of facts begun by Coffin served admirably as a basis for Ferrel's fuller theoretical studies. His first extended report on "The winds of the northern hemisphere" was published in 1853 in the sixth volume of the Smithsonian Contributions. The full discussion of the winds of the globe was only completed by his son after Coffin's death, when it received a general introductory discussion from the competent hands of the Russian meteorologist, Woeikoff. All this subject deserves extended consideration in the next period of our meteorological history. I shall only extract the following reference to storms, which seldom came directly under Coffin's attention. He wrote in 1853 that the irregular motions of the wind are best accounted for—

By supposing that in the general currents of the atmosphere there are occasional eddies (cyclones) in which the air revolves spirally from right to left in the Northern Hemisphere, and from left to right in the Southern, the curve making an angle with the radius vector equal to that which the mean direction of the wind makes with the maximum and minimum line of the barometer, and that the barometer falls in the forward half of these eddies and rises in the latter half, the amount of rise and fall diminishing as we recede from the central axis on either side. * * * Now, it is remarkable that this is the very manner in which the best observations show it (the air) to move in the region of storms, during which it is known that our greatest barometric changes are apt to occur; and our discussion seems to prove that the two great American champions of the law of storms, with those who have followed the one or the other of them on the other side of the water, are both right. The attention of one being chiefly directed to the evidence of rotary motion, he failed to make prominent the inward tendency, though I am aware he has even admitted the probability of its existence; while the other, laboring to establish the latter motion, omitted the former.[1]

This is a clear inductive confirmation of the deduction that Tracy had given ten years before.

[1] Proc. Amer. Assoc., 1853, pp. 89, 91.

The patient labors of Prof. Elias Loomis endured longer than those of any other prominent American meteorologist. He held a high place for half a century, and all who refer to his essays must at once be inspired with a feeling of confidence in the caution and clear judgment of their author. His first articles followed the first of Redfield's by but a few years; and in 1843, when he was studying out with great labor the scattered records of a severe land storm, it appears that he had already perceived that the truth lay between the positions held so strongly by the leaders of that time. He was not satisfied either with Redfield's circles or with Espy's radii, for in all storms he saw "certain common characteristics, namely, an inward motion with a tendency to circulate against the sun" (Trans. Amer. Phil. Soc., LXXIX, 1846, p. 181). It is significant to find the centripetal motion here mentioned before the circular. The same paper closes with a most interesting suggestion concerning the results that would be gained from a year's series of two daily meteorological charts of the United States. It was a happy completion of a busy life for this venerable investigator, not only to see the accomplishment of his early desire, but to work successfully in his advanced years on our wonderful series of weather maps, and produce from them the finest series of inductive generalizations concerning the physical features of cyclonic storms that has yet been published. Just as Coffin's work affords inductive foundation for Ferrel's theories of the general planetary circulation, so Loomis' results give the best series of facts of their time concerning the constitution of cyclones, on whose motions Ferrel labored so successfully.

One of Loomis' conclusions deserves mention here, if only for the satisfaction that it would give to Espy, had he lived to see it. After an extended examination of tropical cyclones he found that while they were still in low latitudes the departure of their inflowing winds from the gradients is on the average only 10°, "a quantity so small that it requires uncommonly accurate observations of the wind to detect the deflection; that is, the wind apparently moves with great velocity directly toward the center of the isobars. This is what Espy called a *spout*. We thus see that tropical storms are spouts, and not cyclones, and it is unfortunate that the term cyclone should ever have been adopted." This interesting extract may be found at the close of the second chapter of the revised edition of Loomis' "Contributions to Meteorology" (New Haven, 1887).

In reviewing this middle division of our meteorological history, I think we have just reason to be proud of our national record. At a period when the chief business of our country was the settlement and development of the great Mississippi Basin, some Americans found time to devote to scientific pursuits, and they applied themselves with such ability and perseverance to their studies that the world is their debtor.

## 9.—SOME REMARKS ON THEORETICAL METEOROLOGY IN THE UNITED STATES, 1855 TO 1890.

FRANK WALDO, PH. D.

It is universally recognized as an almost impossible task to present in their proper light contemporaneous events, when it is desired to show the true relation which they sustain to whatever else is happening at the same time. We can usually follow out the causes which give rise to them, because we can view in perspective, and shorn of details, the course of progress in the development which has finally resulted in the present state of affairs.

I have been asked to present to you some account of the progress in theoretical meteorology in our country during the period which practically embraces the present time. I have just remarked that in the abstract case this is a difficult if not an impossible task, and now must say that in the special case of theoretical meteorology the circumstances are such as to make the present time particularly inopportune for giving, with the degree of certainty which is desirable, an account of the true progress which has been made, and especially that by our countrymen, and the condition of the matter at the present time as measured on the absolute scale of certainty.

A few years ago meteorologists thought that we were at last getting to a quite clear understanding of the principles involved in the cause, maintenance, and dissipation of those phenomena which are associated with what we term theoretical meteorology. I trust that it will be but a very few years hence when this same feeling of satisfaction and security may return. We certainly are far from having it at present, and he would be a very bold man who would venture, without some additional light, to formulate our present knowledge according to the standards demanded by the college student and general reader.

In order to realize the condition in which we find theoretical meteorology at the present time, the proper way would be to trace its growth according to the two main methods of procedure which have been followed, viz, the deductive and inductive methods; and during the past thirty years we have had in these, two great leaders, Ferrel and Loomis. Of course, in the present instance this could not be done, except in a very general manner, and the details must be lacking which you would consider essential features of a true portrayal of the progress which is being considered.

One of our American astronomers, in speaking of the work of the Greenwich Observatory, says that if the observations made at all of the other observatories in the world were destroyed, we could get from this single institution all the data necessary for the construction of theories, tables, etc., to put us again in our present position. Per-

haps it would not be saying too much to claim that from the writings of Ferrel and Loomis alone, our two greatest American meteorologists, one can obtain a very comprehensive knowledge of modern dynamical meteorology.

Since, then, so much ground has been covered by these two investigators, it does not seem advisable to attempt to give in the present instance a minute catalogue of what they have accomplished, and, moreover, I hesitate to claim for them priority of discovery or investigation of many of the points treated by them, but which others have likewise studied. For instance, late publications have made it evident that due credit has never been awarded to the early views of Prof. James Thomson on the question of atmospheric motions; and the work of Brandes, Ley, Köppen, van Bebber, and others covers a portion, at least, of the same ground as that investigated by Loomis. Moreover, any mention of specific claims for our eminent fellow-countrymen would undoubtedly have to be defended from the objections raised by supporters of meteorology in other countries, unless the list of these claims is made much shorter than I should be willing to make it without a very extended comparative review of the recent history of meteorology. I must, therefore, ask to be permitted to confine this communication mostly to a general survey of the importance of the works of our two great leaders, Ferrel and Loomis.

There is such an intermingling of fact with theory in a practical science like meteorology that an exact dividing line can not be drawn between the practical and theoretical investigations, although there is a very great difference in the degree with which one or the other preponderates in the union. Loomis undertook the accumulation and discussion of meteorological observations, while Ferrel attempted to deduce from established principles the laws governing these phenomena. The work of the one may, therefore, be said to be practical, and that of the other theoretical. We will take up, first, Ferrel's theoretical work, or more explicitly stated, his influence on dynamical meteorology.

The first of the dynamical theories is that of Hadley, who, in 1735, gave a most plausible explanation of the cause of the trade winds. At that early time this phenomenon had been so well observed as a matter of necessity to navigation that, in this one case at least, order was brought out of the chaotic conditions which were supposed to prevail among the winds. This was, however, the starting point for all future inquiries. When it was once recognized that the differences in the temperature at the earth's surface, combined with the axial rotation of the earth, gave rise to the peculiar general circulation of our atmosphere, the completion of our knowledge of the subject became a matter of detail. A century later we fine Dové theorizing on

the secondary effects of such a circulation, and Buys-Ballot formulating his keen scrutiny of collected wind observations. Maury shows his strength by collecting and mapping the normal winds of the ocean, but shows his weakness in speculating on a philosophy of their origin. At this point Ferrel, and about this same time James Thomson, promulgated a theory which, with various amendations, we accept at the present time.

Ferrel's theory is the only one which, commencing with the origination of the primary air circulation, logically traces out in full the various grades or degrees of wind movement down to the local puffs or whirls which occupy but a brief space both of distance and time. Ferrel's work has been criticized as being crude when viewed from the modern standpoint of mathematical knowledge; but judged by the standards of his day it could not have been so considered, or it would never have received the sanction of such men as Peirce and Runkle. Mathematical tools were in process of manufacture just after the middle of this century, which have permitted various German physicists to deal with this problem in a manner not heretofore possible, and they have partly covered the same ground that Ferrel had worked, and in many cases improved on his labors.

In speaking of our subject, the pride which we take in the work of William Ferrel might easily tempt us to overstep the bounds of modesty and lay ourselves open to the charge of exaggerating the importance of American contributions. In some instances, however, we are able to avail ourselves of the already expressed opinions of some of the most eminent of European meteorologists concerning the importance of Ferrel's work and the place which he occupies in the development of meteorology. Such, for instance, are the remarks of Wilhelm von Bezold,[1] when he speaks of the introduction of the theorems of general mechanics and thermodynamics (mechanical theory of heat) into the solution of meteorological problems:

> So there was developed a new field of investigation, which, in America where, thanks to the pioneer work of William Ferrel, this new departure had its home, received the name of dynamical meteorology, but which we can better call theoretical meteorology. While such European investigators as Reye, Hann, Guldberg, and Mohn, and others entering gradually upon the field of action, caused this class of investigations to occupy, from year to year, a greater amount of space among the contemporaneous writings.

Sprung, Oberbeck, Köppen, Hann, and others offer us somewhat similar and, in many cases, more special and definite expressions concerning the world's indebtedness to Ferrel. But just here it is desirable to note the enthusiastic acceptance of Ferrel's discoveries by Cleveland Abbe in America, and the briefly expressed early recognition of their value by Henry Blanford and Prof. Everett before the

[1] *Die Meteorologie als Physik der Atmosphäre,* Himmel u. Erde, Berlin. Vol. v, 1892, pp. 1–19.

rest of the meteorological world had awakened to the fact of their existence. This was not so much the fault of continental meteorologists as it was the misfortune of obscurity, which was the fate of so much of the American science literature of that day. For certainly, outside of publications in perhaps two or three of our journals, current American contributions were not much read in Europe thirty-five years ago.

It was thus the fate of one of the most revolutionary contributions to theoretical science offered by an American during this century, to lie unappreciated until its full brilliancy was dimmed by the productions of later analytical tools such as have been used by Guldberg, Mohn, and Marchi, and the long list of German investigators, at the head of whom we ought, perhaps, to put Helmholtz, although he has been the latest one to enter this practical field of research. To Dr. Sprung we owe, more than to any other European, a widespread recognition in Germany of the value of Ferrel's work; and indirectly through Dr. Sprung we probaby owe Dr. Köppen a large debt of gratitude for the part he had in first interesting, I think, and subsequently encouraging, I know, Sprung in making himself so familiar with Ferrel's investigations.

Concerning Prof. Ferrel's work, as a whole, I wish to offer a few remarks, which, I hope, will assist in making clearer the true value of his services to modern theoretical meteorology. Various sketches of Ferrel's life have shown us the nature of his education. He was a self-made man in the sense that his early studies and his studies after graduation from college were pursued utterly independently of supervision; and the later study must have been carried out without any advice even from advanced students of science. We must naturally expect that a man of his character and surroundings would devote himself to the practical application of the subjects studied rather than to any visionary theoretical side, and so we find it. Those persons who have looked upon Ferrel's views as the production of an unpractical theorizer, whose work will not bear transportation to the actual fields of nature, have a very erroneous idea of the man, his work, and his methods. Americans have erred in this matter as much as Europeans, even though we on this side of the Atlantic have known him personally, while they have known him only through portions of his writings. In mentioning this, the thought comes up, what a royal welcome would Ferrel have received at the hands and from the hearts of European meteorologists had he presented himself at their doors in the character of a visitor.

The idea that Ferrel was unpractical has been confined mostly to those meteorologists whom, in the present subdivided state of the science, we should term climatologists. They look over Ferrel's writings and find that he neither made, collected, nor discussed meteor-

ological observations, except in a few cases were they were needed to supply constants for use in developing theories; they find broad questions treated by methods which their former training has not permitted them to thoroughly grasp; and they find many of his deductions to fail when judged according to the accustomed standards of local averages. Many of these questioners of Ferrel's work will doubtless be surprised to learn that in recent years the charge has been made, and more than once, that Ferrel's reasoning is not theoretical enough. Since the attention of a number of able physicists and mathematicians has been drawn to the problems of theoretical meteorology, great strides have been made in the solution of the intricate relationships existing in the air conditions and motions. Many of these investigators, while engaged in their own work, have naturally scrutinized with the utmost care the results previously obtained by Ferrel, and his manner of obtaining them. They have found that in some cases Ferrel has made use of methods which, in the strictest of mathematical sequences, seem to them unwarrantable; and he has likewise made such abbreviations of terms and relations, in order to simplify the problems, that he has omitted as negligible very appreciable quantities.

Now, the fact is that probably not one of the theoretical investigators alluded to have had the quarter part of the experience that Ferrel has had in the matter of the practical effect or the result of the omission of terms in a formula, and in the interpretation of the true meaning of the terms as represented by actual effects in nature. On the other hand it may be asked, how many of the practical meteorologists can boast of a record of several hours a day devoted to actual computations during a period of thirty years? And yet such was Ferrel's work. Certainly his work of so many years on computations covering the observations of tides and their future predictions, and the somewhat analogous work in connection with the preparation of the American Nautical Almanac, gave him such a training in the combination of the highest forms of theory and practice as has not been experienced by any other meteorologist.

There is one feature of Ferrel's work which I am not able to understand, and that is, that nowhere in his writings is there to be found a trace of the influence of the other great writers on this subject; and the lack of mention, of even their names, would lead one who did not know Ferrel personally, to conclude that he had not read the contemporary writings of Guldberg and Mohn, and others. The only plausible explanation is that Ferrel wished his writings to be distinctly individual; but I feel sure that they would have gathered strength and that their permanent future importance would have been very greatly increased if he had made use of contemporary work in his summaries given in his "Recent Advances" and "Winds."

We will now turn to the inductive work of Prof. Loomis, our other leader in meteorology.

Prof. Elias Loomis entered upon the long course of investigation as a meteorologist just at the time when two great rival theories regarding storms were being advocated in a most spirited manner by Redfield and Espy. Both of these men were trying to form theories from inadequate data, and they had, neither of them, hit upon the best method for presenting the data which they did have collected. It was one of Loomis' great contributions to meteorology to supply such a method as was needed for presenting and studying storm data. A great storm of 1836 was carefully studied by Loomis, and although he improved somewhat on the earlier manner of presentation, yet the digression from the beaten path of procedure was not marked, and the tracing of the path of the region of lowest barometric pressure was the chief feature of the investigation; but in 1843 he presented a discussion of a great storm of 1842, in which he introduced changes as radical and as far reaching in influence as Ferrel's great paper on atmospheric motions. The method adopted by Loomis, that of representing the elements of a storm as a whole at any particular time by plotting synchronous observations and drawing lines through points of equal intensity or magnitude, has revolutionized the study of storms, and was the foundation of our modern weather maps.

The fact that Loomis at first used the departures from an average air pressure instead of the actual absolute readings of the barometer in drawing isobars has no important bearing on the real importance of his invention. Loomis urged that one or two years of daily synchronous observations throughout the country would give sufficient data for meteorologists to determine the laws of our storms, and thus complete the true theories of their actions. We have had many times two years of observations of this nature, but we are still a long way from any conclusive theory of the action of the storms; but this is due to the incompleteness of such data, and does not disprove the truth of Loomis' assertion. In fact, in the light of our present knowledge of the subject, we can, after the lapse of fifty years, repeat what Prof. Loomis proposed, and say that what we need to clear up the misty points in our storm theories is a couple of years of *complete* simultaneous observations and their careful discussion. There can be no doubt that real progress would be made if all of the volunteer observing force in the United States would co-operate for even one month each in the spring, summer, fall, and winter (four months in all), by making hourly or bi-hourly observations, and supplementing these by observations at numerous stations of the wind direction and velocity, as shown by freed toy balloons, and further supplementing all of this by exposing, at the greatest altitude possible, registering instruments in captive balloons which are made to ascend and

descend at hourly or bi-hourly intervals, noting the atmospheric pressure, temperature, etc., either continuously or at intervals of 100 feet in altitude, during both the ascent and descent. These last balloon observations should be made at as many stations as possible, although they would necessarily be few in number; if only a very few (say half a dozen) stations could be so occupied, they should be located along a line running from Wisconsin or Michigan southward. We have made so little progress in the accurate knowledge of cyclonic and anticyclonic air movements during the past fifteen years, because there has been no advance in the system of making observations.

Loomis not only mapped out a plan for determining those facts concerning storms which are necessary for the support of any theory of local wind movements, but he at once put it into practice; and during fifty years of his life it was his favorite field of investigation to obtain the facts concerning the origin, growth, maintenance, and dissipation of these systems of air circulation and their coexistent phenomena.

Prof. Loomis was greatly influential in the development of theoretical meteorology, although most of his work was of a practical nature. While Ferrel used observations to test his theories, Loomis busied himself with working up masses of observations, and endeavored to derive from them normal or average conditions; and these he examined, and endeavored to find out the laws governing their characters, and also their mutual relations. There can be no doubt but that Loomis' permanent service to meteorology consisted in amassing facts, and in this he showed an industry and indefatigability not to be met with in any other non-professional meteorologist. His numerous later memoirs are of that substantial nature which contribute to the steady growth of a science. They do not, however, bear marks of a higher order of genius, and individually none of them stand above the work of the better class of meteorological investigators in those countries where the science is cultivated. It was the great number of these investigations, which appeared for so many years with clock-like regularity, which gives Loomis the leading place among our investigators of meteorological facts. It is but justice to other less productive workers to state that for many years Prof. Loomis' financial condition was such as to enable him to have all the assistance he required in his work, and in later years, during the time of his greatest activity in publication, he availed himself of the services of skilled computers and investigators. There can be no doubt but that Loomis' work lost a good deal in individuality by this means, but perhaps the gain in quantity more than makes this up.

Loomis' early investigations of storms, and especially the collection of data concerning tornadoes, were very important as pioneer work. Until the appearance of the book by Reye (*Wirbelstürme*),

Loomis' summary of our knowledge of tornadoes was the most complete yet published. Loomis' later work, which includes the long, semiannually appearing series of papers in the "American Journal of Science," and which were read at the meetings of the National Academy, consists of four more or less distinct fields of inquiry, viz, areas of low atmospheric pressure, areas of high atmospheric pressure, rainfall distribution, and high level meteorology. During the last years of his life he revised his contributions to the first three of these topics and communicated them to the National Academy of Sciences, and they were published in the memoirs of that body. In these investigations Loomis has obtained many of the constants necessary for insertion in formulæ deduced by theory, and without which the theories would lose much of their practical significance. In this direction his work was remarkably successful, and in the various departments which he entered as an investigator there is probably no higher authority than he, and his results have been repeatedly used in many lands. When, however, Loomis attempts to set up theories based on his average conditions, he is not always to be so implicitly followed. The facts are stated with a clearness and precision that convince us of their proper reliability, but the deductions of the theories, or at least some of them, leave the impression that their author was hampered by the array of details of facts in his forming a conception of the general relations of the phenomena investigated. The originality, or inspiration, or whatever we may call it, which permits an occasional individual to see the main features of a matter, shorn of the details which distract the attention from these, does not appear in Loomis' theoretical work as markedly as we see it, for instance, in Ferrel's.

Loomis' many years' study of observations have led him to follow Espy in assigning precipitation as the chief factor in storm development, with the general motions of the air as a secondary element. Ferrel reverses this and assigns the greater effect to the general air motions, but the *origin* is physical rather than mechanical. The latest European school of theorists inclines to the view of the mechanical production of storms by the greater air currents, with precipitation as a secondary phenomenon.

Helmholtz and others have pointed out the great difficulty in reproducing atmospheric events on a laboratory scale. Still, many suggestive ideas can be obtained from the laboratory experiments, and from this point of view they are not to be discouraged. Take, for instance, a case which occurs in connection with the progress of the branch of science which we are now considering. Referring to the paper published by W. B. Rogers, in Silliman's Journal in 1857, in which he treats experimentally of the breaking up of an (for a time) unceasing fluid current into whirls which have an anticyclonal

motion on the right and a cyclonal motion on the left hand side, I believe that if this law had been more fully and surely developed, and had been at once introduced into the theories which attempted to explain the atmospheric movements, we should have had presented to us thirty-five years ago, the theory of air circulation which now seems to be gaining ground in the estimation of meteorologic philosophers, viz, the full effect of the primary circulation on the secondary. As it was, we were obliged to wait for the theoretical development of the subject of fluid motion before the suggestions which have from time to time cropped out concerning this modification of the theories of Dové. It seems to me that the effects of the axial rotation of the earth were insisted on by Ferrel to the full extent of their importance, and this field in which he worked for upward of thirty years has furnished about all that can be gleaned from it. We now need a quantitative determination of the magnitude of the vortical motions which we know from theory and experiment occur in the continuous primary current of the atmosphere. It certainly appears as though these magnitudes must be so far in excess of the deviatory effect of the earth's rotation as to at least greatly mask the effect of this force on the secondary motions.

In the case of the general circulation we must study the primary effects arising from currents of an almost film-like thickness in relation to their breadth, but in the actual action which comes under individual observation, we have such a thickness of air layers as to require totally different treatment, both experimental and theoretical.

Where two or more air layers, which are superimposed one on the other, have different directions of motion, as occurs in the primary circulation, then there will certainly be in some cases, when the direction of rotation is the same above and below, an increase in magnitude of vortical velocity; and in other cases, when the direction is reversed above and below, there will be a diminished magnitude of vortical velocity. A variety of phases would exist for various combinations, or rather degrees of perfectness, of these two simple conditions, and it is these that we would meet with most frequently in nature. It is not my intention to elaborate a theory on the basis of these, what we may term, natural vortical motions, but I do wish to emphasize the fact that they are not sufficiently considered in our American theoretical meteorology. Prof. Cleveland Abbe's treatise on air movements contains many suggestions which will greatly aid in the development of theoretical meteorology in the direction which I have just indicated, and his views should receive the careful consideration of American meteorologists.

## 10.—NOTE CONCERNING A BIBLIOGRAPHY OF AMERICAN CONTRIBUTIONS TO METEOROLOGY.

Oliver L. Fassig.

A history of the progress of meteorology and climatology in the United States has not yet been written. In various journals and reports may be found references to the work of different organizations, which have fostered the science to a greater or less extent, and to the contributions of individuals; but no single historical memoir exists to show the large share due to this country in the development of meteorology.

In the preceding papers of this section the growth of the science in the United States is outlined by means of a series of independent contributions on the work of the various institutions and individuals engaged in developing the science rather than by means of a single connected memoir. As a closing contribution to the series of historical sketches, it was thought desirable to bring together, in the form of an author catalogue, the references to the printed contributions in this country.

The task has been made comparatively easy by the existence of the General Bibliography of Meteorology, compiled by the U. S. Signal Service and the U. S. Weather Bureau. This card catalogue, now comprising about 70,000 titles, was carefully searched, and copies were made of all references to published reports and memoirs by citizens of the United States, so far as they could be identified as such. While the selection was somewhat difficult in the absence of biographical sketches, the percentage of error is small, and it will be mostly eliminated by further research.

Personal visits were made to most of the larger eastern libraries; letters were addressed to living writers in 1884, during the compilation of the general bibliography above referred to, and this will be repeated for contributions since that date.

This national catalogue contains such printed books, pamphlets, and papers, appearing in all kinds of serial publications, as relate directly to meteorology and climatology, but does not include the literature of terrestrial magnetism, nor the applications of meteorology to medicine or to agriculture.

The form of the collection is that of an author catalogue, with very brief biographical sketches, and with a subject index, as this form is the one best suited for a partial bibliography of any subject, such as a national bibliography must needs be.

The catalogue at present extends to the close of 1892, and comprises about 5,000 references to the publications of about 1,600 authors.

## 11.—HISTORY OF THE WEATHER MAP.

Prof. MARK W. HARRINGTON.

The history of meteorology falls into three distinct periods: 1. That preceding the discovery of the barometer in 1643, during which time very little real advance was made. It was practically a folk-lore stage. 2. The period from the discovery of the barometer to that of the general recognition of the cyclonic character of storms. The latter was the work of many men, among whom stand pre-eminent Dové, Redfield, and Espy, and the date is not definite, but may be placed at 1830. 3. The development of the cyclonic theory, from 1830 to the present time, 1893.

One of the most important elements in the development of the third and last stage was the use of the synchronous weather map. Indeed, it was by the employment of such maps (made long after the occurrence of the phenomena which it was desired to investigate) that Redfield, Espy, and others made their principal discoveries. It was not, however, until the current weather map was made—the weather map which is made at the time of the phenomena themselves—that the full harvest of facts due to it was reaped. The harvest obtained from the current weather map was so great that it has laid the basis for the next, and impending, great advance in the science, viz, its full dynamical treatment. Its importance will therefore justify a discussion of its history, and it is to this that this paper is devoted.

For the current weather map two elements were needed, simultaneous observations and immediate collection of the data. Meteorological observations were usually taken at the same local hours, but differing in absolute time. Those of eastern Russia were thus (if at the same local hours) three or four hours earlier in absolute time than those of western Europe, and those of the Atlantic coast of the United States about as much earlier than those on the Pacific coast. The need of absolutely simultaneous observations was recognized early. From 1772 to 1777 Thomas Jefferson (afterwards President of the United States) and James Madison (afterwards a bishop of the Episcopalian Church) took simultaneous observations at Monticello and Williamsburg, both in Virginia, and about 120 miles apart.[1] This appears to have been at the instigation of Jefferson, who was often far in advance of the world on physical as well as political matters. Jefferson drew some interesting conclusions from the observations. About the same time it appears that the idea had occurred to Lavoisier who proposed (probably before 1784) that instruments for such observations should be scattered over France,

[1] Jefferson, Notes on the State of Virginia (1825), pp. 147–149.

Europe, and the world generally, and refers to an earlier proposal of this sort by Borda.[1]

Lavoisier declared, with wonderful foresight, the possibility of forecasting the weather by such proceedings as these, for at least a day ahead, and wrote, "One would think that it would not be impossible to publish each morning a journal of predictions which would be of great use to society."[2] This was, however, impracticable without some rapid means of communication. The matter seems to have appealed so strongly to the public as the case of a want which was decidedly felt that several years after (1793) M. Romme, a deputy, was charged to present to the French Constituent Assembly a scheme for an aërial telegraph, invented by Chappe, approved by the united committees on public instruction and on war. Lavoisier himself became a victim of the French Revolution, and in the political cyclone of the time the plan dropped out of view. The first renewal of a plan of rapid collection of meteorological data which I have been able to find was that of Kreil in 1842.[3] Kreil maintains that the method of aërial telegraph is not sufficient, and proposes the use of an electromagnetic telegraph. This was after the publication of the invention of the telegraph by Morse (1837), but about coincident with its first experimental test between Washington and Baltimore (1842). A similar suggestion is said to have been made by Piddington in the same year, but I have not been able to verify it.[4] In 1846 the same suggestion was made by Redfield;[5] in 1847 by Loomis[6] (by which time the telegraph was in common use), and in 1848 by John Ball in a paper to the British Association for the Advancement of Science.[7] From 1847 on for several years Prof. Henry reported from year to year recommendations for such use, or tentative arrangements which had been made with the telegraph companies. Finally, the proposals took the form of a regular telegraphic service, and this plan was preached by Maury with great persistence from 1851 on for several years.[8]

With the idea of simultaneous observations and the completion of the telegraphic systems the road was clear for the making of the

[1] *Marié-Davy, Météorologie générale* (Paris, 1877), pp. 27–28.

[2] *Ibid*, p. 28.

[3] *Jelinek, Ueber die Priorität der Anwendung des el. Telegraphen zu den Sturmwarnungen; Zeitsch. der Oest. Ges. f. Met.* (1867), pp. 193–200, especially pp. 197–199.

[4] *Ibid*, p. 196.

[5] Amer. Jour. Sci., 1846, II (2), p. 334.

[6] Smithsonian Annual Report, 1848, p. 203.

[7] British A. A. S. Rep. (1848), Abstract, p. 12–13.

[8] Mrs. Corbin, Life of Maury, pp. 79–83. The telegraph was used for advanced information about the weather in 1850 by Mr. Joseph Brooks, manager of line of steamers between Boston, Mass., and Portland, Me. See Prescott, History of the Electric Telegraph, 4th ed. (1866), p. 254.

weather map. As a matter of fact, however, this had been invented and made use of long before the last requirement was fulfilled. The earliest proposal of this sort which I have seen was one by Brandes, in a letter from Breslau, dated December 1, 1816, printed in Gilbert's *Annalen der Physik*[1] in 1817. Brandes there states that he had tried making daily weather maps from newspaper reports and had found them unsatisfactory. He then proposes to get together a service of 40 or 50 stations, scattered from the Pyrenees to the Urals, and make from their reports (received, of course, by mail) a chart for each day in the year. This plan seems never to have been carried out, as his *Beiträge zur Witterungs-Kunde* (1820), which was a study of the weather of 1783, was carried out on the plan of diagrammatic, not geographic representation.

The ideas of the weather map are very similar to those involved in the special studies of storms by Redfield, Piddington, and others, though the latter are special, being the study of individual storms rather than that of the combined elements involved in weather. Still more like the weather maps of to-day are those prepared by Espy. Indeed, Prof. Henry was accustomed to say that Espy was the father of the present weather map, and Mrs. Moorhead quotes him in the following words:[2] "Charts now used in the service (Signal Service) were identical (with some slight modifications) with those the old Storm King (Prof. Espy) constructed for use in the Meteorological Bureau of the War Department when he was at its head."

It was not, however, to the best of the information available, until some time in 1856 that current charts were made of the weather, and this was done by the Smithsonian Institution in Washington. Prof. Henry's own words[3] on this subject are: "The first practical application of the principle we have mentioned was made by this Institution in 1856; the information conveyed by telegraphic dispatches in regard to the weather was daily exhibited by means of different colored tokens, on a map of the United States, so as to show at one view the meteorological condition of the atmosphere over the whole country. * * * The system, however, was necessarily discontinued at the beginning of the war, and has not yet been resumed." These maps were apparently not drawn and naturally were not preserved.

On February 26, 1858, Le Verrier began charting the telegraphic data received by him.[4] These were in manuscript and apparently

[1] Vol. LV, pp. 112–114.

[2] Moorhead, A few Incidents in the Life of Prof. James P. Espy (1888), p. 12.

[3] Writings of Joseph Henry, Smith. Misc. Coll. Vol. XXX (2), p. 453. See also in this volume the "Meteorological work of the Smithsonian Institution", where these dates are somewhat different. My dates are those obtained from the published statements of Prof. Henry.

[4] *Jelinek, l. c.*, p. 196.

were never published. Le Verrier had studied by graphic methods the storm of November 14, 1854, and on February 16, 1855, he submitted to the Emperor a plan for a meteorological telegraphic network over France. In 1856 he began such a system with thirteen stations, reporting by telegraph and eleven by post. He began publishing an international bulletin in 1857 which he made daily on the beginning of 1858. His first predictions for ports were made in 1860. The synoptic charts or weather maps were not published by him until 1863. On September 11, of that year, he printed and published the isobars and winds for September 7 and September 10, one and three days after their respective dates. On September 16, 1863, he printed the weather map for that day and this has been continued, I believe, without interruption from that day to this.

This was the first current weather map published. It gives daily the isobars and winds for central and western Europe, from St. Petersburg to Palermo and westward. It is in black and white, 170 millimeters broad by 140 high. The winds are indicated by arrows which fly with them, the velocity being indicated by feathers on a scale of 6. The isotherms and clouds and rains were not entered until April 24, 1878, and were then given by means of an additional map. From that time to this the *Bulletin International* has contained two maps.

In 1869 Prof. Cleveland Abbe, with the assistance of the Western Union Telegraph Company, began the collection and use of telegraphic weather reports at Cincinnati, Ohio, and on February 2, 1870, Mr. Armstrong, local manager of the telegraph company, undertook the making of weather maps and their multiplication to a limited number by a manifold process. These maps were continued until October 10, 1870, when they were relinquished on account of the daily maps then undertaken by the Signal Office. These maps gave about 30 stations from the Atlantic seaboard westward to Houston, Tex., Omaha, Nebr., and Cheyenne, Wyo. They extended northward to Halifax, N. S., and southward to Habana, Cuba. Their size was 386 by 315 millimeters. They gave the temperatures, cloudiness, rain, snow, and direction of the wind, but not the pressures. No meteorologic lines were entered on the maps. These were the first current weather maps in the United States, and copies are now very rare. For the opportunity to examine the set, I am indebted to Prof. Abbe.

The official American system of weather maps began with the tri-daily maps, November 1, 1870. They were in manuscript, and were made both at Washington, D. C., and Chicago, Ill. They were multiplied so as to be properly published only at Washington from January 14, 1871, and the printing of the morning maps began on May 2, 1871. The first maps contained reading of barometer and

thermometer, wind direction, clouds, and precipitation, but no lines. The isobars began to be inserted on October 30, 1871, and the isotherms April 15, 1872.

The next series of current weather maps was that of the British Meteorological Office. They first appeared printed in the bulletin for March 23, 1872, though from a report of the Meteorological Committee[1] of the Royal Society it appears that they began on March 11. Probably the earliest maps were in manuscript. The maps of these bulletins were daily, and consisted of four at each issue; the first for isobars; the second, isotherms; the third, wind and sea; and the fourth, clouds, rain, etc.

All the current weather maps issued, with dates at which they were begun, are given in Table I.

Copies of these maps for the dates January 1–5, 1892, were kindly sent, on request, to the Weather Bureau library where they have been compared. The only exception to the above date has been for the Spanish maps, which were begun in 1893. The copy of this map examined is for April 2, 1893.

In the case of the Belgian, British, French, and Saxon services the weather map is in two equal parts, one for isobars and winds, the other for isotherms and (usually) precipitation. In the Bavarian issue the isothermal map is smaller than the other. In the German issue, besides the two larger maps for the day of issue, there are two smaller ones for the day before, making four maps with each issue. In the Italian issue there is an additional smaller map (three in all) of the isobars placed with the forecasts.

All are in black lines on blue water and white land, except the German which is black and white, the Swedish which is blue on white, and the Australian which is red and purple on white sea and yellow land.

In size the maps vary from 565 by 400 millimeters (American) to 98 by 134 millimeters (British). The Australian is next in size to the American (550 by 387 millimeters).

In Japan the map is yet tri-daily. In America it was formerly tri-daily, but is now bi-daily. The Russian maps are bi-daily. The remainder (15 in number) are daily, and all, except the Australian, are issued on Sunday.

The hours of observation, outside of Europe are:

For the United States, 8 a. m. and 8 p. m., seventy-fifth meridian time.

For Australia, 1 p. m. and 4 p. m.

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[1] Rep. Met. Com. Royal Soc., 1871, pp. 43–44, with specimens of chart for May 4, 1872. From this it would appear the maps began March 11, 1871, but it was probably 1872.

For Japan, 6 a. m., 2 and 10 p. m., one hundred and thirty-fifth meridian time.

For India, 8 a. m.

For Algeria, 7 a. m. (Same as France.)

For European countries, the hours are:

7 a. m., Austria, France, Russia (and 9 p. m.), and Switzerland.

8 a. m., Germany, Italy, Bavaria, Sweden, Great Britain, Belgium.

9 a. m., Spain.

For Europe, therefore, the maps that cover more than one country are not made with sychronous observations. If the above times are local (proper), then the observations would be in Greenwich time from 2 a. m. (in western Asia) or 5 a. m. (in western Russia) to 8 a. m. (in western Europe), a difference of three to six hours. If they are the times of the respective capitals, the difference in absolute time would be about three hours. If all are in Greenwich time, the difference is about two hours.

The territory covered by the maps is as follows:

Algerian.—Tripoli to Finland, westward.

American.—United States and southern Canada.

Australian.—Australia and New Zealand.

Austrian.—Greece to Russia, westward, except Spain.

Bavarian.—Italy to Finland, westward, except Spain.

Belgian.—Bavaria to Scandinavia, westward.

British.—Bavaria to Gulf of Bothnia, westward.

French.—All Europe and Algeria.

German.—Sardinia to North Cape; Ireland to Kiev.

Indian.—India.

Italian.—France to central Austria, southward.

Japanese.—Japan.

Russian.—France to North Cape, eastward to Obi River.

Saxon.—Austria to Finland, westward.

Spanish.—Spain.

Swedish.—Finland to Saxony, westward.

Swiss.—Greece to Finland, westward, except Spain.

The forecasts or probabilities are given on all the maps but the Algerian. In the American, Australian, Bavarian, Belgian, German, Japanese, Russian, and Swiss, they are definitely for "to-morrow." For the British, they end at noon "to-morrow." In the Austrian, French, Indian, Italian, Saxon, and Spanish, they are indefinite as to time covered. The floods are forecasted in France and the United States.

A synopsis is published on all the maps and comprises a statement of weather conditions prevailing with reference generally to the changes in the last twenty-four hours. Often these latter statements are tabulated. The tabular statement, with or without change since

last map, is given in each case for a number of stations varying from 5 for Belgium and 12 for Saxony to 123 on the French map, 128 on the Indian, 130 on the American, and 138 on the Russian.

The wind scale employed is in 3 grades on the German, Saxon, and Swiss maps; 4 on the Australian, British, Italian, Spanish, and Russian; 6 on the Austrian, Bavarian, Belgian, French, Japanese, and Swedish; and 7 on the Indian maps. It is not given on the American maps. The international symbols are usually employed on the European maps but not elsewhere. The type for the Australian and Japanese maps are the American symbols. The Australian map makes an excellent distinction between the rain which has fallen and that which is falling. The American symbols include a shading for a rain area and an inclosing line for the region where the temperature has fallen or risen 20° F., or more, in twenty-four hours.

There are some special features of individual maps which deserve special note. The French map is the most truly international. It even contains the general conditions in the United States for the day before. The British gives its "probable changes" and forecasts separately. The Russian map has its explanations in Russian and French. On the Australian map the forecasts for different colonies are made by different persons. The Swiss map gives a tabular statement of sunshine at 6 stations. The Belgian and Algerian give the automatic trace of barometer, thermometer, and hygrometer for the preceding twenty-four hours. The Saxon map has 9 types of forecasts which it gives for the four quarters of the day at each of 9 stations. The British map is reprinted in the London "Times."

In addition to the bi-daily weather map issued at Washington, 73 stations of the United States issue maps independently, each for a considerable area about the station, as a center. There were thus issued 8,830 maps, daily, on June 1, 1893, of which 6,257 were issued in the morning and the remainder in the evening. For details of this service see Table II.

These maps are of uniform size, 750 by 325 millimeters. They are in black lines on white and blue, like the Washington map. The isobars, isotherms, wind, state of sky, and rain are given, with a brief tabular list of rainfall, weather, or river notes, on the right-hand margin, and a forecast for a limited area for the next day in the lower left-hand corner. The rain areas are given on many, and on some are marked out areas of decided rise or fall of temperature. These are the maps which are most broadly distributed to the public in the United States. They are multiplied by the milliographic process, and in some cases are reduced and printed in daily papers of large circulation.

In addition to the current weather maps already noted, there are

others, the issue of which is delayed, though they are in all proper senses, daily weather maps. Among these the most important are:

1. *The Standard Weather Chart of Australasia.*—This is issued by the Queensland Post and Telegraph Department at Brisbane, Australia. It is made by Mr. Clement L. Wragge. A rough map is made on time and posted in Brisbane. The completed map is held for ships' news. It is the largest weather map issued, being 23 by 18.5 inches. It covers the whole of Australasia and surrounding region from E. 40° to W. 140°, and from S. 60° to N. 40°. The issue was begun in 1887. The map examined was that for March 28, 1892.

2. *Hoffmeyer's Cartes Synoptiques Journalières.*—These charts were made by Dr. N. Hoffmeyer and issued by the Institut Météorologique Dansois, Copenhagen, Denmark. They covered the North Atlantic and the most of Europe, and are daily maps for the period from September 1, 1873, to November 30, 1876. They were published from three to six years after their date. Continuations of this series were made with the aid of the Hamburg *Deutsche Seewarte* from December 1, 1880, to November 30, 1884.

3. *Atlas des Mouvements Généraux de l'Atmosphère.*—These maps were issued by the Observatoire Impériale de France. They covered the North Atlantic Ocean and western Europe. They were daily maps from June 1, 1864, to December 31, 1865, and were printed at Paris, 1868–'69.

4. *Synchronous Weather Charts.*—These were issued by the Meteorological Council, London, England, covering daily the North Atlantic and adjacent land surfaces for the thirteen months, August 1, 1882, to August 31, 1883. They were printed in London in 1886.

5. *Bulletin of International Meteorological Observations taken Simultaneously.*—These were taken daily and published by the Signal Service from six months to one year after date. In 1882 the title was changed to "Bulletin of International Meteorology." Quarto charts were published from October 1, 1877, to December, 31, 1884, and from October 1, 1886, to December 31, 1887. The maps from January 1, 1885, to September 30, 1886, remained in manuscript. A folio edition was printed separately from July 1, 1884, to December 31, 1884, and from October 1, 1886, to December 31, 1887. The territory covered was the entire Northern Hemisphere.

In conclusion, it is interesting to see what parts of the earth's surface have been covered by weather maps and for how many years they are available. They are as follows:

Europe, since September 16, 1863.

North Atlantic, 1864 (from June 1), 1865, 1873 (from September 1), 1874, 1875, 1876 (to November 30), and from October 1, 1877, to December 31, 1887.

United States and southern Canada, since January 1, 1871.

TABLE I.—*Current weather maps.*

| Country. | Place of issue. | Date of beginning of issue. | | Responsible service. | | | Names. | | Present director. |
|---|---|---|---|---|---|---|---|---|---|
| Montgomery, Ala. | a. m. | | 26 | | 26 | July 1, 1887 | Jan. 24, 1888 | May 10, 1892 | |
| Nashville, Tenn. | a. m. | | 56 | | 56 | Oct. 1, 1887 | | | |
| New Haven, Conn. | a. m. | | 169 | | 169 | Sept. 1, 1887 | Oct. 19, 1888 | Mar. 2, 1891 | |
| New Orleans, La. | a. m. | | 121 | | 121 | July 1, 1887 | | | |
| New York, N. Y. | a. m. | p. m. | 313 | 349 | 662 | Aug. 2, 1886 | | | |
| Norfolk, Va. | a. m. | | 90 | | 90 | July 1, 1887 | | | |
| Omaha, Nebr | a. m. | | 119 | | 119 | Nov. 7, 1891 | | | |
| Parkersburg, W. Va | a. m. | | 32 | | 32 | Aug. 13, 1891 | | | |
| Pensacola, Fla. | a. m. | | 25 | | 25 | July 15, 1889 | | | From June 15 to September 15, annually. |
| Philadelphia, Pa. | a. m. | | 193 | | 193 | Sept. 1, 1886 | Oct. 19, 1888 | Nov. 21, 1889 | |
| Pierre, S. Dak | a. m. | | 62 | | 62 | Jan. 5, 1893 | | | |
| Pittsburg, Pa | a. m. | | 116 | | 116 | July 1, 1887 | | | |
| Portland, Me | a. m. | | 122 | | 122 | Oct. 1, 1887 | | | |
| Portland, Oreg. | a. m. | | 81 | | 81 | Oct. 15, 1892 | | | |
| Raleigh, N. C. | a. m. | | 75 | | 75 | Mar. 29, 1892 | | | |
| Rochester, N. Y | a. m. | | 97 | | 97 | July 1, 1887 | Sept. 15, 1888 | July 8, 1892 | |
| St. Louis, Mo. | a. m. | p. m. | 205 | 122 | 327 | July 1, 1887 | | | |
| St. Paul, Minn | a. m. | | 113 | | 113 | Dec. 13, 1889 | | | |
| Sandusky, Ohio. | a. m. | | 38 | | 38 | July 1, 1887 | | | |
| San Francisco, Cal. | a. m. | p. m. | 259 | 95 | 354 | Apr. 17, 1891 | | | |
| Sault Ste. Marie, Mich | a. m. | | 60 | | 60 | May 25, 1892 | | | From December 1 to April 1, annually. |
| Savannah, Ga. | a. m. | | 36 | | 36 | July 1, 1887 | | | |
| Shreveport, La. | a. m. | | 59 | | 59 | Apr. 1, 1891 | | | |
| Sioux City, Iowa. | a. m. | | 169 | | 169 | May 1, 1890 | | | |
| Springfield, Ill. | a. m. | | 39 | | 39 | Feb. 10, 1887 | | | |
| Springfield, Mo | a. m. | | 22 | | 22 | Oct. 13, 1892 | | | |
| Tampa, Fla. | a. m. | | 32 | | 32 | Nov. 22, 1890 | | | From April 1 to October 31, annually. |
| Toledo, Ohio. | a. m. | | 106 | | 106 | July 1, 1887 | | | |
| Vicksburg, Miss. | a. m. | | 180 | | 180 | May 26, 1890 | | | |
| Wilmington, N. C | a. m. | | 74 | | 74 | July 1, 1887 | | | |
| Total. | | | 6,257 | 2,573 | 8,830 | | | | |

NOTE.—Oswego, N. Y., published a. m. maps from July 1, 1887, to September 21, 1887; Baltimore, Md., from October 15, 1886, to October 19, 1888, and Port Huron, Mich., from June 1, 1888, to December 10, 1888. Number of stations issuing a. m. maps, 58; p. m. maps, 4; both a. m. and p. m. maps, 11; total, 73.

Japan, since March 1, 1883.
Western Siberia, on the Russian map, since May 12, 1889.
Australia and New Zealand, since January 1, 1877.
Australasia, since 1887.
India, since October 13, 1887.
Indian Ocean, February, 1861, and since 1887.
Algeria, since April 8, 1877.
Northern Hemisphere, from October 1, 1877, to December 31, 1887.

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## 12.—BRIEF SKETCH OF THE DEVELOPMENT OF METEOROLOGY IN MEXICO.

RAFAEL AQUILAR Y SANTILLAN.

Meteorological investigation in Mexico has acquired considerable importance since the establishment of the *Observatorio Meteorológico Central* in 1877. Before that the government had no observatory where work of an official character was conducted with regularity. Up to that time all that was done was due to private enterprise, and was conducted in order to study the local climates. These private observatories were at times overworked, and often the expenses of their installation were met by charging fees for their results. This work was done without definite plan, and there was no serial publication of their observations, which, owing to change of residence and death, were often discontinued for want of a capable successor to carry them on. By this means we have only comparative data relating to various parts of the country.

The first observations of which we have any data were made about the middle of the eighteenth century by the wise Father José Antonio de Alzate y Ramirez. This illustrious clergyman was born in the town of Ozumba, Mexico, in 1738, and died in the Capital City in 1799. He was a talented observer, and with rare zeal and fidelity he devoted himself to the study of natural science, in which he became so distinguished that the Royal Academy of Sciences in Paris made him a corresponding member, a most honorable distinction, as he is the only Mexican who has ever possessed it up to the present time. His most important works have been published, among which are *Diario Literario de México* (1768); *Asuntos varios sobre Siencias y Artes* (1772, 1773); *Observaciones sobre la Fisica; Historia Natural y Artes Utiles* (1787); and his famous *Gaceta de Literatura de México* (1788 to 1795). 8vo. 3 vols. In all of these there is a great deal of interesting research, and much relating to physics of the globe and meteorology. They reveal the climate of localities, the nature of instruments invented abroad, and disseminate and recommend similar researches. For eight years he regularly took meteorological observa-

tions, to which he refers in his *Descripción Topográfica de México*, but of which, unfortunately, we only have the record for the last nine months of the year 1769 in *Observacionés Meteorológicas de los ultimos nueve meses del año* 1769. (Mexico, 1770. 8vo.)

Comparing these observations with those made by means of more perfect instruments, the careful accuracy of Alzate's observations is demonstrated, the only discrepancies found being reconcilable with the period in which he lived. Alzate was the first to determine the absolute elevation of the City of Mexico.

For a long period after P. Alzate there were no meteorological observations. In 1824 the editors of *El Sol* published at the Capital daily meteorological observations, by some one unknown, from June 14, 1824, to January 14, 1828. Dr. José Burkart took some observations in 1826, and in 1839–'40 he made observations of the temperature in the mining regions of Veta Grande, Zacatecas, and subsequently in those of Flalpujahua. He also determined the altitude of different parts of the Republic in several of his journeys.

In the Capital City of Mexico there was a series of creditable observations, viz: By Don Francisco de Gerolt, 1833–'34, and by Sr. Don José Gómez, Conde la Cortina, from 1841 to 1845; the latter also published in the *Boletin de la Sociedad Mexicana de Geografía y Estadística* many of his researches in terrestrial magnetism and earthquakes. The Conde la Cortina is prominent among Mexican meteorologists for his zeal and ability.

Meteorological observations were published at various times in the periodical *El Mexicana* by members of the geographical section of the staff of the army from 1842 to 1843; by the School of Mines from 1850 to 1858, but with several intermissions; by Sr. Eng. Ignacio Cornejo, of the said school, from 1863 to 1866; by Sr. Eng. Francesco Jiménez in 1858. About this time a meteorological observatory was established in the convent of Santa Clara by Prof. Andres Poëy, assistant of the French Scientific Expedition, who published the results of his researches in *El Diario del Imperio* and in the *Comptes Rendus* of the French Academy of Sciences. (Paris, August 20, 1866.)

Sr. Juan de Mier y Terán, professor of physics in the National Preparatory School, took meteorological observations from 1868 to 1875. In 1875 Sr. Isidor Epstein took three observations daily.

The *Observatorio Meteorológico Central* was founded by the Minister of the Interior, Vincente Riva Palacio, and commenced its work on March 6, 1877. The personnel consisted of Sres. Mariano Bárca, director; Vincente Reyes, sub-director; and Miguel Pérez, to whom were subsequently added Sres. José Zendejas and José L. Collazo. Sr. Reyes began the series of hourly observations which have been continued up to the present time. He left in 1880, after having published his highly meritorious work. (See *Bibliografía Meteorológico*

*Méxicano*, 1890.) He established the Department of Magnetism with instruments which he understood perfectly, and with which he made the most elaborate and regular series of observations of the magnetic elements that have ever been made in Mexico. He published a description of these instruments and his methods of observing in an interesting book, *Memoria sobre el Departmento Magnético del Observatorio Meteorológico Central* (Mexico, 8vo, 1878 and 1885). This book has gone through two editions, and is still the text book of the School of Engineers, and is consulted with advantage by many engineers and meteorologists.

Meteorological observations in different parts of the country have been characterized by a similar lack of definite plan and regularity.

Bevard made a series of observations in the Gulf of Mexico, from August, 1838, to July, 1839. Dr. J. L. Berlandier made a series of observations at Matamoros for a period of nine years and two months, during the years 1830 to 1851, observing at the hours of 6, 8, 9, and 10 a. m. and 1, 2, 3, 4, 5, 6, and 8 p. m. Dr. Burkart, as previously mentioned, took thermometrical observations in 1839 and 1840, at Veta Grande, and subsequently at Flalpujahua. By means of observations of the barometer and hypsometer he determined the altitudes of 365 places, and established the barometric profile from San Blas to Tampico.

Observations were made on the estate of San Nicolás, Buena Vista (Xochimilco, D. F.), for twenty-one years, from 1855 to 1875, by persons unknown. The naturalist, Dr. José Appolinario Nieto, took observations at Córdoba, Vera Cruz, from 1856 to 1863, and sent them for publication to the *Sociedad de Geografía*, which also published his tables for the reduction of barometric pressures from 260 to 855 millimeters. He was one of the most zealous students of the science of meteorology, and repeatedly offered to the Minister of Interior plans for the establishment of meteorological stations throughout the entire country, with a regularly organized service. Sr. Eng. José Ramón de Ybarrola, a graduate of the National School of Agriculture at San Jacinto, D. F., made observations in 1857 and 1858, which were published in the *Boletin de la Sociedad de Geografía*.

From 1858 to 1868 Don Carlos Sartorius observed at the estate of Mirador, in the State of Vera Cruz. Don Miguel Velázquez de Leon commenced a regular series of observations at the estate of Pabellón, State of Aguas Calientes (east of Aguas Calientes), in 1869, which have been continued by his sons with the same zealous accuracy up to the present time. In Colima, Don Gregorio Barreto made observations of the temperature and rainfall from 1869 to 1880. In Queretaro, Eng. José M. Romero began a series of observations in 1870, which have been kept up to date by Prof. Pascual Alcocer. In Guadalajara, Prof. Lázaro Pérez observed from 1874 to 1886. In

Monterey, Don Isidor Epstein observed in 1865. In Cuernavaca, Vincente Reyes, whose work has been mentioned, observed in 1873, 1874, and 1876. In Puebla, Don Joaquin de Mendizábal Tamborrel, a topographical engineer, observed in 1872 and 1873, while a professor of physics in the State College. In San Juan Michapan, Vera Cruz, Prof. Manuel M. Cházaro observed in 1872 and 1873, and subsequently at Tlacotalpan. At Puebla, Rev. Pedro Spina, S. J., began a series of observations in 1876, which have been kept up to date. Finally, with the founding of the *Observatorio Central*, interest in the observations has been aroused and gradually various stations have been established, some by private individuals and some by the states.

At present the following observatories are engaged upon meteorological work, viz: The observatories of Mexico, Tacubaya, and Mazatlan, supported by the Ministry of Interior; the observatories in Puebla, Saltillo, and San Luis Potosi, supported by the Jesuit Fathers; the observatories in Morelia and Zapotlan, supported by the Archbishops of Michoacán and Guadalajara, respectively; the private observatories of Dr. M. T. Andrade, at Huejutla; of Velázquez de Leon (Joaquin and Luis) at the estate of Pabellón; and that of Juan Lafforêt, in Tuxpam; the state observatories at Aguas Calientes, Campeche, Guadalajara, Guanajuato, Leon, Oaxaca, Puebla, Queretaro, Pachuca, San Luis Potosi, Toluca, Tuxtla Gutierrez, Tampico, Vera Cruz, and Zacatecas.

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## 13.—ENGLISH METEOROLOGICAL LITERATURE, 1337-1699.

G. J. Symons, F. R. S.

This paper must commence with a few general remarks. All that it deals with is at least one hundred and ninety years old, much of it is much older; it is, therefore, essential to endeavor to realize the conditions of English meteorologists at that time.

In the first place we must remember that Caxton, the first English printer, did not begin work until 1477, when the art of printing had spread to most of the capitals of Europe; therefore, we can not expect the productions of the English press in the fifteenth and sixteenth centuries to rival the volumes issued at that period in Venice, Rome, and Paris.

Another point which must not be overlooked is the fact that Latin was largely used by cultured Englishmen up to a somewhat late date; and there is reason to believe that, during the whole period of which I have to treat, foreign editions of the works of Aratus, Aristotle, Lucretius, Pliny, Virgil, and others were largely used in England.

We must remember, also, another complication resulting from this backwardness of English printing, namely, that works by English

authors were (probably for cheapness) often printed on the continent. To establish that fact I quote one book in my own possession, Flud's "Philosophia Moysaica," especially as it is of interest in showing that, by whomsoever first invented, the earliest recorded use of a thermometer was not by Drebbel or Santorio, but by an English doctor, Sir Robert Flud, M. D., Oxford, who was born at Milgate, in Kent, in 1574, traveled on the continent for several years, then settled and practiced in London, where he died September 8, 1637.

I have other volumes by Flud containing weather predictions, etc., published at Frankfort; but the one with the engraving of the air thermometer (and in which he speaks of it as having been described in a manuscript more than 50 years old, i. e., 1588, at the latest) is a small folio; a full page of text is 10¼ by 5 inches; it is not paged but folioed; there are 8 preliminary pages and 152 numbered folios; the title is "Philosophia Moysaica, in qua sapientia et scientia creationis et creaturarum sacra, verèque christiana (vt pote cujus basis sive fundamentum est unicus ille lapis angularis Iesus Christus) ad amussim et enucleatè explicatur. Authore, Rob. Flvd, alias de Flvctibvs, Armigero et in Medicina Doctore Oxoniensi. Govdæ, excudebat Petrus Rammazenius bibliopola, anno M. D. CXXXVIII."

This subject, treating of the place of printing, has been a difficult one upon which to decide. For instance, the first English edition of Jonstonus' "Thaumatographia" appeared in London in 1657, small folio, being "Written by Johannes Jonstonus, and now rendered into English by a Person of Quality." The first edition which I have was issued at Amsterdam in 1632, and there is nothing except the name to suggest that the writer was an Englishman, and there is absolutely nothing to show that he was a resident in England; yet, when we come to the 1657 edition, entitled "An history of the Wonderful things of Nature," we find a preface, dated London, May 15, 1631. Hence, the Latin editions of 1632 and 1633 might very fairly be claimed for England, although published at Amsterdam. It would, however, be an almost endless task to try to apportion all works to the countries in which they were written, and I have, therefore, resolved to refer only to books printed and published in England; so, of course, this has the disadvantage of occasionally including the works of foreign authors. Another rule, which I must adopt in order to keep this paper within a reasonable length, and which will add to its value in one respect, but render it very incomplete, is to describe only books which I actually possess. Although this limits the list very much, it excludes all possibility of doubt as to the existence of the books. To make the work even approximately complete is impossible until the United States Government issues that *magnum opus* the Meteorological Bibliography, for which meteorologists all the world over are waiting.

I am aware that the decision to refer only to my own books appears egotistical, but I can see no alternative, for with many thousand titles of books still unsorted, it is quite out of the question to go through them in order to pick out early English printed books; it would take weeks to do it and, after all, would certainly leave some undescribed. I, therefore, adhere to my decision, and will describe only what I actually have, but occasionally refer incidentally to earlier editions.

I shall also clear the ground by making one general reference to the storehouses of notes upon meteorology which exist in the early volumes of the "Philosophical Transactions of the Royal Society of London," and in the histories of that society by Spratt and by Birch.

1337.

Although printed in 1891, it may be permissible to mention that in the Bodleian Library at Oxford there is (as far as is at present known) the earliest continuous weather record in the world. By the kindness of the Bodleian authorities I was allowed in 1891 to have it photographed, and a few copies of the photographs and of a literal translation of the text were printed. Unfortunately, I have only one copy or I would have sent one for inspection by the Congress. There are, however, at least three copies in the United States, one in the library of the U. S. Weather Bureau, one in the private library of Prof. Cleveland Abbe, and one at the Blue Hill Observatory. The record (first monthly and then daily) was kept partly at Oxford and partly in Lincolnshire, by the Rev. William Merle, Rector of Driby, near Alford, and is continuous from January, 1337, to January 10, 1344. Apparently the weather at that time (more than five hundred years since) was very similar to what it is now.

1508.

I have heard that Wynkyn de Worde (the second English printer) issued a work upon meteorology, but I can not trace any such book. As far as I am aware, the only scrap of printing by Wynkyn de Worde which can be regarded as meteorological is the following, which is in "The Kalender of Shepeherdes," 1508.

OF A THONDER STONE THAT FELL IN THE DUCHY OF AUSTRYCHE.

How be it that the impressyons here above semeth of thynges meruaylous to people that have not sene thē, they saye that it is in party impossyble. Know they and other that in the yere of our Lorde m.lxxxxij [should be mccccIxxxxij] the vij daye of novembre a meruayle happened in the earldome of Ferrate in the Duchye of Austryche, nyghe a towne named Enszheim, whereas that daye was greate thonder and orage. In the playne feldes nyghe the sayde towne fell a stone of thonder, which weighed ii hondred and fyfty pounde and more. The whiche stone to this present tyme is kepte in the sayde towne, and every man and womā may se it that wyll.

Before proceeding with the notes upon my collection of early Eng-

lish printed works on meteorology, there is one reason for its incompleteness which should be mentioned. Unfortunately, many rich men, who can not read the books when they have purchased them, will pay enormous prices for early printed English books, merely as curiosities, and thus the few copies which occur for sale are gradually being locked up, away from those who would use them.

1605.

Confirmation of this fact, and of what I said previously as to the lateness of printing in England, is afforded by the fact that the earliest English printed book in my collection is as late as 1605, 120 years after the first edition of Firminus (Venice, 1485) and of P. D'Ailly. It is a small quarto by T. Digges, the son of Leonard Digges, by whom the work was first issued in 1555.

Of this work there are in the British Museum Library editions dated 1555, 1556, 1567, 1576, 1578, 1596, and 1605; and in the library catalogue of the University of London I see editions of 1574 and of 1594.

The book is a small quarto and is chiefly astrological, half the title page being taken up with an engraving of a man surrounded by the signs of the zodiac and lines indicating the parts of the body influenced by each. Digges' "Prognostication Everlasting," from its 5th to its 14th leaf, deals with the weather, and is based in about equal proportions upon the rules of the astrologers and upon quotations from Aristotle's "Meteorology."

1607.

The next book is on the boundary between history and meteorology; it is entitled "1607. A true report of certain wonderful overflowing of Waters, &c.," it is also a small quarto, and in 1884 an edition of 200 copies of a reprint was issued with facsimiles of the title page and of the first page.

1631.

Edward Brerewood (whose name is misspelled upon the title page of this edition of his work, published in 1631, eighteen years after his death) was one of the early professors at Gresham College. His little book, *De Meteoris,* was edited and published by Mr. T. Sixesmith, M. A., of Brazenose College, Oxford. Although it occupies only 71 pages, small octavo, it is divided into four books, with about 80 sections and a multitude of subsections. It is written in a very argumentative style, and though the author frequently quotes Aristotle, he seems to attach more weight to astrology, and he is continually speaking of the influence of the sun, moon, and planets, though I can not see that he explains anywhere how this influence is conveyed or how it acts.

1634.

Latin editions of Pliny's "Natural History," dating back to 1469, had been accessible to wealthy Englishmen, and I believe that the first edition of Dr. P. Holland's translation into English appeared in 1601. Mine is, however, the reissue of 1634. As is well known, Pliny's work may be regarded as an epitome of the knowledge of natural phenomena at the commencement of the Christian era, and its claim to notice here rests upon the large portion of the second book, which is devoted to the consideration of meteorological phenomena, such as halos, coronas, parhelia, paraselenæ, rainbows, auroras, meteors, bolides, rain, hail, frost, snow, thunder, lightning, clouds, winds, typhoons, and earthquakes.

1639.

The next book is one of which the author was a Frenchman, Libertus Fromondus (or Froidmont), a professor at the College of Louvain, whose six books of meteorology were issued first at Antwerp in 1627 and reprinted at Oxford in 1639. It is a small octavo of rather more than 500 pages, and, though retaining the old idea of three regions in the atmosphere, of the influence of comets, and many other exploded notions, is interesting as giving in a single treatise an epitome of the views held by Ammonius, Aristotle, Cardanus, Ovid, Pliny, and Virgil. As far as I am able to judge, it seems a fair summary of the knowledge obtained up to that date.

1643.

"Speculum mundi," by John Swan, comes next on my list in 1643, but this is the second edition, a small quarto. The first appeared in 1635. It is partly theological, being based on the early chapters of Genesis; but Chapter V deals with mock suns and moons, halos, auroras, comets, *ignes fatui*, meteors, thunder, lightning, clouds, rain, dew, hail, snow, mists, and wind. This is an extremely interesting and popular treatise on meteorology, but it occupies 504 small quarto pages, and it is quite impossible to do justice to it here. Some of the notions are, of course, very funny; for instance, the author, after giving a very reasonable account of the phenomenon known as *ignis fatuus*, or will-with-the-wisp, goes hopelessly astray and confuses it with St. Elmo's fire by saying that, "Moreover, when the like matter chanceth to be fired in some such part of the aire as is over the Sea, then these lights appear to marriners, and are called *Castor* and *Pullux*, if there be two at once; otherwise *Helena*, if there be but one."

1653.

The next work to claim notice is evidently the appendix of some larger work, as the pagination begins with 177 and 178; then follows 253, the verso of which is 184 followed by 181, with the verso of 256 followed by 157 (probably a misprint for 257), with the verso 258,

after which they follow in proper order to *finis*, on page 303. It has a regular title page, entitling it "A tract concerning the weather, etc., by N. S., a wel-wisher to the *Mathematics* and that noble art of Astrologie." It is almost entirely astrological, and chiefly based upon the works of Ptolemy.

Of "The Naturall and Experimentall History of the Winds," by Francis Bacon, Lord Verulam, Latin editions were printed at Leyden in 1638 and 1648, but the first translation into English and the first publication in England were not until 1653.

1654.

The next book on my list said to be by "W. F., Doctor in Divinitie," was written by Dr. W. Fulke, master of Pembroke Hall, Cambridge, who died in 1589. My copy is a very late edition. I believe that the first was issued in 1563, with the title of "A goodly gallery with a most pleasant Prospect into the Garden of Naturall Contemplation to behold the Naturall Causes of all kinds of Meteors as well fyery and ayery as watry and earthy, etc." London. 8vo. It was re-issued with a fresh title page in 1571. There are said to be editions of 1634 and 1640, and then follow 1654, 1655, and 1670, all of which I have. It is a small book, but treats shortly of nearly the same subjects as *Speculum mundi*. I quote the section upon dew:

> Dew is that vapour which in Spring and Autumn is drawn up by the Sun in the day-time, which because it is not carried into the middle region of the Air, abiding in the lower region, by cold of the night is condensed into water, and falleth down in very small drops. * * * There be Three things that hinder Dew from falling; that is, great heat, great cold, and wind; for Dew falleth in the most temperate calme time.

1655.

Another edition of Fulke.

1656.

Another edition of Fromondus.

1657.

See *ante* respecting Jonstonus' "Thaumatographia."

1659.

Another edition of Brerewood.

1660.

"New experiments physico mechanical touching the spring of the air by the Honourable Robert Boyle" (1660) may hardly be regarded as meteorological, but there are many references to meteorological matters, e. g., to name only three, the cause of a defective vacuum at the top of some barometers, the repetition of Pascal's experiment as to the decrease in the length of the column of mercury on carrying it up a mountain, and the cause thereof.

1661.

"An attempt for the explication of the phenomena observable in an

experiment published by the Hon. Robert Boyle by R. Hooke" (1661). Although quoted in relation to barometers, this paper is scarcely meteorological. Hooke tries to explain the rise of liquids in capillary tubes.

1662.

"Mirabilis annus secundus, or the second year of Prodigies" (1662), is a curious collection of accounts of auroras, parhelia, meteors, thunderstorms, lunar halos, paraselenæ, chiefly, if not wholly, in the years 1661–1662. I think (but am not sure) that this list of extraordinary events was published annually for five or six years. I do not know the author's name.

"Tractatus de restitutione corporum, in quo experimenta Torricelliania et Boyliana explicantur. Autore Gilberto Clerke," 1662, 8vo. An epitome of the views of Descartes, Hobbes, and the author, as to what fills the space above the mercurial column in a barometer tube. The author evidently had a very imperfect vacuum, because he says that glass must be porous, because if he put his warm hands upon the upper part of the tube the mercury began to sink. This is, of course, always the case when there is air above the column.

1664.

"Danielis Sennerti D. Vratislaviensis, Epitome naturalis scientiæ. Editio ultima, Oxford," 1664. The preface is dated Wittenberg, Saxony, 1618, in which year a quarto edition was published there; an octavo edition was printed at Oxford in 1632, a folio edition in London in 1661, and the above 12mo in 1664. The author devotes the ten chapters of Lib. IV (about 70 pages) to meteorology, and gives fuller quotations from classic authors than any other writer of his period. I notice references to Aristotle, Hippocrates, Horace, Livy, Lucretius, Plato, Pliny, Plutarch, Seneca, Valerius Maximus, and Virgil.

His references to mediæval writers are nearly equally useful, there being several of whom I have not previously heard. Although, necessarily, some of his theories and explanations are wide of the mark, many of them show close observation, such, for instance, as that hail falling towards the end of winter and the beginning of spring is generally opaque.

1665.

My edition of "New Experiments and Observations Touching Cold," by the Hon. Robert Boyle, is the first, and is dated 1665. This very thick 12mo of nearly 1,000 pages is particularly interesting for the full account of Boyle's early experiments with thermometers, and for his quickness in noticing that unless they were hermetically sealed it was difficult (especially with air thermometers which he often used) to separate the indications of temperature from those produced by variations of atmospheric pressure. Although much of

his theory was entirely wrong, his love of truth is constantly evident, and many of his facts are very interesting.

This same year, 1665, gave us another work of special interest to the microscopist, Hooke's "Micrographia," a small folio of about 250 pages, and with 38 large plates. Although primarily a treatise upon the microscope of those early times and giving greatly magnified engravings of various objects, Hooke at each end of the book runs away from his subject. In the preface he fully describes and engraves the wheel barometer first invented by him; on page 91 and in Plate VIII he deals with, and gives engravings of, snow crystals; and toward the end he deals with astronomical refraction, the formation of clouds, and the nature of the surface of the moon, illustrated by a large map of part of the moon's face.

1667.

"Observations, both, Historical and Moral, upon the burning of London, September, 1666, * * * also an Essay touching the Easterly-winde." By Rege Sincera, quarto pamphlet, 1667. The writer notes the dryness of the east wind, which he ascribes to its course being overland nearly all the way from China, and dwells upon its prevalence in March, April, and the early part of May.

A reissue of Hooke's "Micrographia." Not a new edition, as it is, with the exception of the title page and one plate, worked from the original type and plates of the 1665 edition.

1669.

"Systema Agriculturæ, the mystery of Husbandry discovered." By J. W.[orledge], Gent. Small folio, London, 1669. This contains not only remarks upon meteorology in relation to agriculture scattered all through it, but (on pages 247 to 264, inclusive) the fullest collection of weather proverbs published up to that date.

1670.

Another edition of Fulke.

"The Shepheard's Legacy or John Clearidge, his Forty Years experience of the Weather." 8vo. London, 1670. Excessively scarce. I do not know of another copy; it is the earliest edition of what has since been reprinted many times as "The Shepherd of Banbury's Rules for judging the weather," Lowndes says, "attributed to John Campbell, LL. D.," but that is incorrect, as this edition was issued about 30 years before Campbell was born. Though the name is spelled Clearidge on the title page, it is given as John Claridge, of Hanwell, near Banbury, at the end of the preface, and I know of no reason for assuming the name to be fictitious. It is a thin octavo of probably 32 pages, but as my copy has been most carefully remounted page by page, although there is the word finis on page 30, I am not certain that there may not have been another leaf damaged beyond repair.

Another edition of Fromondus. London, 8vo.

1671.

"A discourse concerning the Origine and Properties of Wind with an Historical Account of Hurricanes and other Tempestuous Winds." By R. Bohun, Oxford. 8vo. This treatise of 302 pages is noteworthy as among, if not absolutely, the first in which the theories of the winds, as propounded by Aristotle and partly adopted by Bacon, are compared with details of the trade winds, monsoons, typhoons, and winds from other parts of the world, of which the classical authors knew nothing. The preface shows that the author might almost rank as a Maury nearly two centuries before the great American promoted the Brussels Conference. I think that the reprint of the first paragraph of the preface is desirable.

THE PREFACE.

Considering the unsuccessful attempts of several Authors who have adventur'd upon this difficult part of Meteorology, I was sufficiently discouraged from exposing to publick view those Collections, which I had sometime made concerning the Causes and Properties of Winds. But afterward, by reason of my residence in a place principally concern'd in Naval Affairs (where I had frequent opportunities of conversing with the most experienced of our Sea Captains), I began to compare the observations of their Voyages, with the writings of the most celebrated of the Ancient, and Modern Philosophers, which I judg'd the only expedient to arrive at a more perfect History of Winds. I have omitted nothing remarkable which was taken notice of by ARISTOTLE, whose Sagacity in these enquiries was the greatest that the Grecian World could boast of. But the succeeding Ages, which with their nice Speculations endeavour'd rather to amuse, than satisfy the minds of men, made little Progresse in the History of Nature, till our Voyages to the East and West Indies, and the great increase of Navigation for these Hundred years last past, furnisht us with so many new discoveries, and improvments in all Natural knowledge (especially, in what relates to the Motions of the Winds and Seas) that we are every day forc'd to regret the insufficiency of those Theories which we receiv'd from the Schools of the Ancients, since the Course of the GENERALL OR TRADE WIND, the INDIAN MONSOONS, the severall sorts of BRISES in the AFRICAN. and AMERICAN CLIMATES (which are certainly the most considerable PHENOMENA that belong to an exact Treatise of WINDS) were as remote from the knowledge of their most inquisitive Naturallists, as the places where they happen, from ATHENS or ROME.

"Tracts written by the Hon. R. Boyle about * * * the temperature of the Subterraneall regions," etc. 8vo. Oxford, 1671. The tracts on temperature refer to the rise of temperature in deep mines and to an original idea of cooling wine at sea in the tropics, viz, by lowering the bottles over night to 80 or 100 fathoms and pulling them up when required, thus showing that at that day they were aware of the stratum of cold water below the hot surface layer of some parts of the tropics.

"Caroli Claromontii, Doct. Medici, Nob. Lothargingi. De Aëre, locis, & aquis terrae Angliae," etc. 12°. London, 1671. This is a curious little book, written in London by Dr. Claromontius, who was visiting the country. It is chiefly medical; much of it is in Greek, and

the general style is very similar to the well-known work of Hippocrates.

1674.

"Difficiles Nugæ, or Observations Touching the Torricellian Experiment, and the Various solutions of the same, especially touching the Weight and Elasticity of the Air." 8vo. London. This anonymous work is attributed to Sir M. Hale, who died two years after it was published. It may, I think, be regarded as the final attempt at supporting the old notion that "Nature abhors a vacuum."

"A true and perfect narrative of the Great and Dreadful Damages Susteyned in Several Parts of England by the late Extraordinary Snows," etc. Small 4to. London, 1674. The nature of this tract is sufficiently indicated by the title.

1675.

"Zymologia Physica, or a brief Philosophical Discourse of Fermentation * * * whereby * * * Earth-quakes, Eruptions, &c., likewise the appearance of Meteors * * * are genuinely solved." By W. Simpson, M. D. 8vo. London, 1675. Dr. Simpson was, I believe, practicing as a physician at Scarborough, and this book has an appendix upon the mineral water at Knaresborough. The author seems to have tried the effect of mixing sulphur and niter, and to have convinced himself that mineral waters, hot springs, volcanoes, earthquakes, St. Elmo's fire, meteors, and even the occasional luminosity of the sea were all due to mixtures of these two bodies with water or vapor.

1681.

Another edition of Worledge.

1683.

Another edition of "Boyle on Cold."

"Natural Philosophy improven by new experiments touching the Weather-Glass, the Hygroscope, etc., by G. S. [Sinclair]." Sm. 4to. Edinburgh, 1683. The character of this work will be gathered from the headings of some of the sections: "Experiments showing why the mercurial cylinder rises and falls as it is carried up or down through the air." "Cause of the suspension and keeping up of the water in weather glasses." "Why, under water 34 feet deep, the height of the mercury in a baroscope is 58 inches." "Observations on a considerable thunder with great lightning, in East Lothian, in July, 1670."

1684.

"Essays of Natural Experiments made in the Academie del Cimento. Englished by Richard Waller." 4to. London, 1684. The only English edition of the excellent work issued in 1666 and in 1667 by the members of the Academy del Cimento. It is quite impossible here to give an adequate account of this celebrated work, which, in

many respects, laid the foundation of modern physics, and, incidentally, was most useful to meteorology. Some of the instruments used by the academicians remain to this day, and are marvels of glass blowing.

1685.

"De Origine Fontium." By Robert Plot. 16mo. Oxford, 1685. This work was undoubtedly suggested by the anonymous (but really by Perrault) book, published at Paris in 1674, "De l'origine des Fontaines," and it seems to me, though I have not read it all, far inferior to the French work. Dr. Plot seems disinclined to accept Perrault's calculations of the rainfall over the basin of the Seine and the flow down that river, and gives vague statements as to rivers in all parts of the then known world, but not a single record of rainfall to compare with them.

1686.

"Astrometeorologia or Aphorisms and Discourses of the Bodies Coelestial," etc. By J. Goad. Folio. London, 1686. A work of 514 pages, by far the largest and most important work devoted to Astrological Meteorology. I am not aware whether the few persons who still believe in planetary influence upon local weather accept this writer's views, and I do not myself think it necessary to set them out in detail, but I think that he should receive the credit due to the enormous labor involved in the preparation of this book. If two copies of it could be purchased, and the various facts recorded in it could be rearranged in chronological order, they would form a history of earthquakes, thunderstorms, tempests, miraculous showers, auroras, pestilences, etc., more nearly perfect than any other book, perhaps, than any three books in any language, which I could name.

1688.

"A complete discourse of the nature, use, and right managing of that Wonderful instrument the Baroscope or Quick-Silver Weather-Glass by John Smith." 8vo. London, 1688. An excellent manual for the construction of barometers, the author being fully aware of the capacity error and urging the adoption of large cisterns in order to minimize it. He proposed two brass scales, one graduated to inches and tenths, with a sliding pointer; the other with the usual words, fair, etc., but "change" was to be 30 inches, *not* 29½, as is now usual. He further urged strongly the importance of the mercury being very pure. It appears that in those early days the tube was sent empty, as full instructions are given as to how the frame was to be suspended, the tube and the mercury cleaned (through chamois leather), and the tube filled on its arrival at its destination. Mr. Smith was evidently far ahead of most persons of his time. He, in the last three pages of his book, explains why Dr. Wallis's barometer

did not rise so high as that of the Hon. Robert Boyle (want of capacity in the cistern), why Dr. Beal's read higher in cold mornings and evenings than at mid-day (air at top of tube), and why a barometer was reported in the "Philosophical Transactions" No. 55 to have two errors: (1) for the first three years it usually rose in the heat of the day, (2) subsequently it did the reverse:

The cause did undoubtedly proceed from the Quick-Silvers being not well purged from air, and that air in the body of the mercury being expanded by the Heat, did cause the Quick-Silver to swell, and by consequence rise higher, whereas, when by time, it had got free into the head of the glass, by expanding there, the contrary effect did follow.

1690.

"Astrometeorologia sana sive Principia Physico-Mathematica, quibus Mutationum Aeris, Morborum Epidemicorum, Cometarum. Terræ-Motuum, etc. Insigniorum Naturæ Effectuum Ratio reddi possit." By J. Goad. 4to. London, 1690. Another book by Goad, this being in Latin with many quotations in contracted Greek. Evidently Goad was not merely, as we have seen before, very industrious, but also extremely well acquainted with nearly all the writers who had preceded him and had written either upon astronomy or meteorology. However mistaken we may consider him to have been, I myself would write with all respect of one who was evidently not merely a very industrious man, but one who seems to have known by heart the works of all the best authors upon his subject from Aristotle to Kepler.

1692.

"The General History of the Air." By the Hon. R. Boyle. 4to. London, 1692. This book is in many respects incomplete, owing to the author's illness and death before it was published, but it is a very useful one, full of facts and much more systematically arranged than those in most of Mr. Boyle's works.

"Jacobi Rohaulti Tractatus Physicus Gallice emissus et recens Latinitate donatus." 8vo. London, 1692. Although a general treatise on physics, astronomy, and physiology, this book may be mentioned as containing nine chapters, occupying about 50 pages, devoted exclusively to meteorology. I do not remember that any earlier writer had called attention to the fact that sexangular snow was not usual, except at low temperatures, and that at higher ones the angles were rounded, nor do I know of earlier reference to pyramidal soft hail than that of in Rohault's section *De grandine pyramidali.*

1693.

"Epistola ad Regium Societatem Londinensem qua de nuperis Terræ-Motibus disseritur, et Veræ eorum causæ eruuntur." By J. Goad. 4to. London, 1693. A demonstration (?) that the eruption of Ætna, December 28, 1692, was due to certain aspects of Mars and Mercury.

1694.

"Horological Disquisitions concerning the nature of Time * * * to which is added the best Rules for the ordering and use both of the Quick-silver and Spirit Weather-Glasses." By John Smith. 8vo. London, 1694. The latter part is a revised and abridged edition of the work by the same author mentioned under date 1688.

"An entire body of Philosophy, according to the principles of the famous Renate Des Cartes * * * written originally in Latin by the learned Anthony Le Grand, now carefully translated * * * by Richard Blome." Very thick folio. London, 1694.

Although, doubtless, copies of the Amsterdam (Latin) editions of Des Cartes' works found their way to England in the middle of the seventeenth century, I can not trace any publication of them in England, either in Latin or English, prior to this huge volume compiled by Anthony Le Grand, It is a puzzle to me to see that it is called a "translation," because it does not agree with either of the Latin editions which I have, viz, Amsterdam, 1664 and 1677. It follows the general arrangement of Des Cartes, but that seems to be all. I think that Le Grand read a chapter of Des Cartes, then closed the book, and proceeded to write his own chapter upon the same subject. The result is, of course, useless as a translation of the "Meteora" of Des Cartes, but it is a very interesting illustration of the state of knowledge at the end of the seventeenth century. The chapters devoted to meteorology would probably fill 100 octavo pages, but besides these there are scraps of meteorology scattered through the volume; for example, in the chapter on the moon we have the following lines and a very reasonable explanation of them:

> The Pale Fac'd Moon, gives Rain;
> When Red, 'twill flow amain:
> But when she's Fair and Clear,
> Like Weather will appear.

1696.

"New observations on the Natural History of the World of Matter * * * and a treatise on Meteorology." By the Rev. T. Robinson. 8vo. London, 1696. This is a very eccentric book written by the rector of a little village in the most thinly populated part of Cumberland; the 44 pages devoted to his treatise of meteorology are, perhaps, what might have been expected from an author living two centuries ago in a spot entirely cut off from access to the centers of knowledge, but they are of interest in one respect, namely, that they give the earliest description yet known of the strong local wind, known in that district as the *helm wind*.

1697.

"The knowledge of Things Unknown, shewing the effect of the

Planets compiled by Godfridus * * * with the Shepherd's Prognostigation for the Weather." 8vo. London, no date. A chronology on page 145 is completed to 1694, and the date of 1697 is given on page 135. I have heard of editions of 1663, 1671, 1688, and 1729, but have only the above. The work is chiefly a series of predictions as to coming events, and especially as to weather. It seems to be based chiefly upon Albertus Magnus, Alkindus, and Ptolemy, but there are many weather proverbs quoted which I do not remember having seen before.

1698.

"Specimen Philosophia Naturalis * * * accedit De Fontium Fluviarumque Origine ex Pluviis, dissertatio physica." By T. F. Casper Bartholinus. 8vo. Oxford, 1678. Contains 16 pages "De Aere et Meteoris," besides 25 pages "De Fontium origine."

1699.?

"An account of a portable barometer, with reasons and rules for its use." By Gus. Parker. 8vo. London, MDCXCX. I give the date as it stands, evidently a misprint. Watt's *Bibliotheca Britannica* gives two editions, 1699 and 1710, that may be, or they may be two guesses at the date. There is no engraving in my copy, nor in the text any reference to one, but the so-called barometer seems to have been a brass cylinder charged with air and then closed, and the observation to have consisted in weighing it very carefully, subject, therefore, to errors from temperature and from dilatation when the pressure was very low, or from compression when it was very great; it would indicate roughly the specific gravity of the air, and so with the barometric pressure. It does not seem to have occurred to the author, who was, apparently, also the maker of these instruments, to make his weights correspond with, say, tenths of an inch of the barometer. Perhaps he tried it and found it difficult.

I have now completed the rapid survey of these 50 books and pamphlets. I do not feel satisfied with the manner in which I have done it. It is not easy to give in so limited a space an adequate description of a row of books which fill a shelf nearly five feet long; and it is especially difficult for one who "has small Latin and less Greek" to grasp within an hour or two the leading characteristics of a volume of 300 or 400 closely printed pages of Latin, sprinkled throughout with paragraphs of contracted Greek, but that is what I have had to attempt many times, and doubtless in some cases I may have misrepresented the author's views, but certainly it has not been consciously or intentionally.

## 14.—CONTRIBUTION TO THE BIBLIOGRAPHY OF METEOROLOGY AND TERRESTRIAL MAGNETISM IN THE FIFTEENTH, SIXTEENTH, AND SEVENTEENTH CENTURIES.

Prof. Dr. G. HELLMANN.

The bibliography of meteorology is still in its infancy. While some branches of the exact sciences, namely, astronomy and mathemathics, possess valuable general and special bibliographies, there are but few preparatory studies for a bibliography or for a history of meteorology. Especially the earlier literature is as yet little known. This can not be simply extracted from bibliographies and catalogues, like the meteorological literature of recent date, but is found scattered in works of a more general character, namely, in those of astronomical, cosmographical, or similar contents, upon whose title pages the word meteorology is frequently not found. Hence, it is necessary to have these older books on hand and to examine carefully their contents.

In the beginning of February of this year, I received a request from Mr. Oliver L. Fassig to prepare a paper giving a general survey of the older German and Italian literature of meteorology for the Chicago Meteorological Congress. Thereupon I replied that I could not undertake an exhaustive treatment of this very interesting subject, owing to the brief time at my disposal. I must moreover restrict myself to a brief description of such books relating to meteorology and terrestrial magnetism published prior to 1700, as are contained in *my own* library.

Though, in consequence, no claim of completeness can be made for this contribution, still the following catalogue contains the greater share of the most important writings of the fifteenth to the seventeenth centuries. At all events, there is no meteorological institute which possesses at the present time the *older* literature to an equal extent.

Owing to lack of time I could consider only *books* proper, disregarding pamphlets (mostly dissertations, disputations, etc.).

In the first part (I. Authors) the titles are arranged alphabetically according to authors' names. I have copied the titles with just sufficient accuracy to be understood; for typographical reasons greater exactness in the reproduction of titles, with reference to orthography, the division into lines, etc., could not be observed. To judge of the extent of a work, the number of leaves, ff., or of pages, pp., is given. The numbers inclosed in parentheses ( ) indicate unnumbered, those not inclosed, numbered leaves of pages.

Owing also to lack of time, I have made but brief remarks relating to the character of the contents, to the scarcity, etc., of the books;

however, whenever possible, I have given references to general bibliographical works where further information concerning the books and their authors may be found. For this purpose I have employed the following abbreviations:

**Bierens de Haan.**—Bibliographie Néerlandaise Historico-Scientifique des ouvrages importants dont les auteurs sont nés aux 16e, 17e, et 18e siècles, sur les sciences mathématiques et physiques avec leurs applications. Par le Dr. D. Bierens de Haan. In Boncompagni's Bulletino di Bibliografia e di Storia delle Scienze Matematiche e Fisiche. Tom. xiv and xv. Rome, 1882 and 1883. 4to.

**Brunet.**—Manuel du Libraire et de l'Amateur de Livres...... Par J. Ch. Brunet. Cinquième édition. Paris, 1860–1865. 6 vol. 8vo. Supplément...... Par M. M. P. Deschamps et G. Brunet. Paris, 1878–1880. 2 vol. 8vo.

**Gamba.**—Serie dei Testi di Lingua e di altre opere importanti nella italiana letteratura scritte dal secolo xiv al xix, di Bartolommeo Gamba da Bassano...... Quarta edizione. Venezia, 1839. I vol. Large 8vo.

**Graesse.**—Trésor de Livres Rares et Précieux ou Nouveau Dictionnaire Bibliographique...... Par J. G. Th. Graesse. Dresde, 1859–1867. 6 tom. in 7 vol. 4to. Supplément, Dresde, 1869. 1 vol. 4to.

**Hain.**—Repertorium Bibliographicum, in quo libri omnes ab arte typographica inventa usque ad annum MD., typis expressi ordine alphabetico vel simpliciter enumerantur vel adcuratius recensentur. Opera Ludovici Hain. Stuttgartiae, 1826–'38. 4 parts in 2 vols. 8vo.

**Hellmann.**—Repertorium der Deutschen Meteorologie. Leistungen der Deutschen in Schriften, Erfindungen und Beobachtungen auf dem Gebiete der Meteorologie und des Erdmagnetismus von den ältesten Zeiten bis zum Schlusse des Jahres 1881. Von G. Hellmann. Leipzig, 1883. 1 vol. 8vo.

**Libri.**—Catalogue of the Mathematical, Historical, Bibliographical, and Miscellaneous Portion of the Celebrated Library of M. Guglielmo Libri. London, 1861. 2 parts. Large 8vo.

**Lowndes.**—The Bibliographer's Manual of English Literature......By W. Th. Lowndes. New edition......By Henry G. Bohn. London, 1858–1863. 9 parts. 8vo. Appendix. London, 1880. I vol. 8vo.

**Picatoste.**—Apuntes para una Biblioteca Cientifica Española del Siglo xvi. Estudios biográficos y bibliográficos de ciencias exactas, fisicas y naturales y sus inmediatas aplicaciones en dicho siglo por Don Felipe Picatoste y Rodriguez...... Madrid, 1891. 1 vol. Large 8vo.

**Riccardi.**—Biblioteca Matematica Italiana dalla origine della stampa ai primi anni del secolo xix compilata dal Dott. Ing. Pietro Riccardi. Modena, 1870–1880. 2 parts in 3 vol. 4to.

**Watt.**—Bibliotheca Britannica; or a General Index to British and Foreign Literature. By Robert Watt. Edinburgh, 1824. 2 parts in 4 vol. 4to.

In part two (II. Subject Index) I have arranged the works enumerated in part one, in various groups, according to their contents. From this it will be evident how one-sided the old meteorological literature is. The main groups are, meteorology in general, weather prophesying, and astro-meteorology. Some new and interesting information may also be gained by grouping the authors of antiquity and of the middle ages who have written upon meteorology. This list is, of course, not complete, as, of the works of some of the

authors not mentioned here, I possess only the editions which appeared *after* the year 1700.

The third part (III. Chronological Index) shows, in chronological arrangement, the works referred to in the first part.

Finally, we may inquire what part different nations have taken in the production and publication of the works mentioned in part one.

Classing the writers according to nationality, they arrange themselves as follows: Germans, 67; Italians, 44; French, 29; English, 26; Greek and Roman, 13; Dutch, 8; Spanish and Portuguese, 6; Arabians, 5; Belgians, 4; Swiss, 4; Greeks, 2; Danes, 1; Swedes, 1.

This shows, as could be expected, that my library is only rich in old German and Italian works. The preponderance of Italian literature has also an inherent explanation; for in the seventeenth century Italy contributed perhaps more to meteorology than all the remaining nations of Europe.

Arranging the books according to the language in which they were written, it becomes evident that *savants* of the fifteenth to the seventeenth centuries comparatively seldom employed their native language in writing books.

There were written in Latin, 157; German, 37; Italian, 34; French, 21; English, 14; Dutch, 4; Greek, 3; Spanish, 2.

## I.—AUTHORS.

**Accademia del Cimento.**

1. Saggi di natvrali esperienze fatte nell' Accademia del Cimento sotto la protezione del Serenissimo Principe Leopoldo di Toscana e descritte dal segretario di essa Accademia. In Firenze. Per Giuseppe Cocchini all'insegna della stella. MDCLXVI......Fol. (8) ff. cclxix pp. (8) ff.

   Many figures in the text and a portrait of the Grand Duke of Tuscany, Ferdinand II, before the title. Scarce original edition. Important for the early history of meteorological instruments.

2. [The same title.]......MDCLXVII......

   Exactly the same edition with another date of issue. *Gamba* (852) and *Riccardi* (407) say that the copies of the first edition with the year 1666 were not sold, but only donated by the founder of the Academy, Card. Leopoldo de' Medici, to other princes.

3. [The same title.] Seconda edizione. In Firenze. Nella nuova stamperia di Gio: Filippo Cecchi. MDCXCI......Fol. (8) ff. cclxix pp. (11) ff., last blank. With many figures and a portrait of the Grand Duke of Tuscany, Cosimo III, before the title.

4. Essayes of natural experiments made in the Academie del Cimento, under the protection of the most Serene Prince Leopold of Tuscany. Written in Italian by the secretary of that academy. Englished by Richard Waller, Fellow of the Royal Society. London, printed for Benjamin Alsop...1684. 4to. (12) ff. 160 pp. (5) ff., 19 plates and engraved title.

**Albohazen Haly.**

Albohazen Haly filii Aben-Ragel libri de ivdiciis astrorum, summa cura & diligenti studio de extrema barbarie uindicati, ac latinitati donati, per Antonium Stupam Rhaetum Praegalliensem. Additus est huic authori index capitum singularum octo partium, seu librorum, quo lector facilius inueniat quaestionem sibi oblatam. Basileae ex officina Henrichi Petri. Fol. (9) ff. 410 pp. (1) f. [In fine :] Anno MDLI.

The last chapters contain astro-meteorological matter. *Graesse* (I 59).

**Alexander Aphrodisiensis.**

Alexandri Aphrodisiensis maximi peripatetici, in quatuor libros meteorologicorum Aristotelis, commentatio lucidissima, Alexandro Piccolomineo interprete. Cui accessit eiusdem Alexandri Piccolominei de iride brevis tractatus : in quo quamplurima Aristo. & Alexandri Aphrodisiensis, ac Olympiodori dicta planissime explicantur. Quae omnia nuper maxima sunt diligentia castigatą: addito indice etiam eorum, quaę in commentatione Alexandri obseruatione digna annotatu sunt. Venetijs, apud Hieronymum Scottum. MDLXI. Fol. (2) ff., 129 pp. (1) f. blank. Woodcuts. *Brunet* (I 161). *Graesse* (I 70).

**Alhazen.**

Opticae thesaurus Alhazeni Arabis libri septem, nunc primum editi. Eiusdem liber de crepusculis & nubium ascensionibus. Item Vitellionis Thuringopoloni libri x. Omnes instaurati, figuris illustrati & aucti, adiectis etiam in Alhazenum commentarijs a Federico Risnero......Basileae, per Episcopios. MDLXXII. Fol. (4) ff. 288 pp. (4) ff. 474 pp. (1) f. Woodcuts.

Scarce. *Brunet* (I 180). *Graesse* (I 77). For an earlier edition of the optics of Vitellio see this article.

**Alkindus** and **Gaphar.** [**Alchindus.**]

1. Astrorū iudices { Alkind' / Gaphar } de pluuijs imbribus et vētis : ac aeris mutatiōe. Venetijs Anno Dni. 1507. Ex officina Petri Liechtenstein. Small 4to. (14) ff.

**Alkindus** and **Gaphar.** [**Alchindus.**]—Continued.

Scarce original edition. Latin translation of two Arabian astro-meteorological tracts. *Graesse* (I 62).

2. Alkindus de temporum mutationibus sive de imbribus, nunquam antea excussus. Nunc vero, per D. Io. Hieronymum à Scalingijs, emissus. Parisiis. Apud Iacobum Kerver, sub duobus gallis, in via Iacobea. MDXL. Small fol. (4), 25 ff.

On the back of fol. 18 begins: Incipit liber Japhar de mutatione temporis. The title proves that the original edition of the work was unknown to the editor Hieronymus à Scalingijs.

[**Almanacs.**]

A collection of 9 English almanacs for the year 1683, bound together in one volume, in 12mo:

1. Merlini Anglici Ephemeris: or, astrological judgments for the year 1683. By *William Lilly.*
2. Nuncius coelestis: or, the starry messenger...... By *Henry Coley......*
3. Calendarium astrologicum...... By *Thomas Trigge......*
4. Merlinus redivivus...... By *John Partridge......*
5. (Title wanting.)...... By *T. Gadbury......* (incomplete.)
6. (Title wanting.)...... By *Saunders......*
7. Bowker, 1683. An Almanack ..... By *James Bowker......*
8. Speculum perspicuum vranicum...... By *Lancelot Coelson......*
9. The Protestant Almanac...... By *Philoprotest......*

All these almanacs contain forecasts of the weather.

**Amontons**, Guillaume.

Remarques et experiences phisiques sur la construction d'une nouvelle clepsidre, sur les barometres, termometres & higrometres. Par Mr. Amontons. A Paris. Chez Jean Jombert...... MDCXCV. 12mo. (16)ff. 170 pp. (5)ff. 8 folding plates, engraved title.

**Apianus**, Peter. [His German name was **Bienewitz.**]

1. Cosmographiae introductio cum quibusdam geometriae ac astronomiae principiis ad eam rem necessariis. MDLIIII. Small 8vo. 31, (1) ff. [In fine:] Impressum Venetijs per Francisci Bindonis..... MDLIIII. *Brunet* (I 342). *Graesse* (I 159).
2. Cosmographia Petri Apiani, per Gemmam Frisium apud Louanienses medicum & mathematicum insignem, iam demum ab omnibus vindicata mendis, ac nonnullis quoque locis aucta, & annotationibus marginalibus illustrata. Additis eiusdem argumenti libellis ipsius Gemmae Frisij. MDLXXIIII. Antverpiae, apud Christophorum Plantinum, sub circino aureo. 4to. (2), 64, (2) ff. With movable figures and with woodcuts and maps in the text. Cap. xv. De ventis. First edition isued in 1527.

**Argoli**, Andrea.

Andreae Argoli serenissimi senatus Veneti equitis et in Patauino lyceo mathematicas profitentis Pandosion sphaericum in quo singula in elementaribus regionibus, atque aetherea, mathematice pertractantur. Editio secunda emendatior, & auctior. Patavii, MDCLIII. Typis Pauli Frambotti......4to. (12) ff. 354 pp. Woodcuts and plates.

Meteorology on pp. 23 to 47. *Graesse* (I 194). *Riccardi* (49).

**Aristotle.**

1. Aristotelis Stagiritae de coelo libri quatuor, de generatione & corruptione libri duo, meteorologicorum libri quatuor, ex optimis exēplaribus graecis iuxta literā recogniti. Cū scholijs, argumentis, ac varietatibus lectionū nuper additis......Venetijs apud Hieronymum Scotum. 1541. 8vo. 518 pp. (1) f.

**Aristotle**—Continued.

2. Aristotelis Stagyritae meteororum libri quatuor: cum Auer. Cordubensis exactiss. commentarijs denuo acutissime traductis: ac deniq; characteribus qui apprime ad inueniendas cuiuslibet capitis sententias conducunt in margine adiectis......Lugduni. Apud Iacobum Giunctam. MDXLII. 8vo. 92 ff., last f. blank. Woodcuts.
3. Meteorologicorum Aristotelis libri quatuor. Francisco Vatablo interprete. Lugduni. Apud Theobaldum Paganum. 1559. Small 8vo. 128 pp. With woodcuts.

[**Astro-Meteorology.**]

Des Himmels Lauffes Wirckung, vnnd natürliche Influentz der Planeten, Gestirn vnd Zeychen, ausz grund der Astronomei nach jeder zeit, jar, tag, vnd stunden Constellation......Zu Franckfort bei Chr. Egenolffs Erben. 4to. (8), 108 ff. [In fine:] Anno MDLVI. With many woodcuts in the text.

Scarce. Contains almost the whole "Wetterbüchlein" (see *Reynman*) and the "Bauern-Practick," two German meteorological chap-books, published separately in the 16th century. *Graesse* (V 311, article "Planeten-Buch").

**Bacci**, Andrea.

1. De thermis Andreae Baccii Elpidiani, medici, atque philosophi, ciuis Romani, libri septem. Opus locupletissimum, non solum medicis necessarium, verumetiam studiosis variarum rerum naturae perutile. In quo agitur de universa aquarum natura, deq; differentiis omnibus, ac mistionibus cum terris, cum ignibus, cum metallis, de lacubus, fontibus, fluminibus ...... Venetiis, MDLXXI. Apud Vincentium Valgrisium. Fol. (32) ff. 509 pp. 1 fold. plate.

   Deals also with rainfall, inundations, etc. First edition of this esteemed work. *Graesse* (I 270).
2. Del Tevere di M. Andrea Bacci medico et filosofo libri tre, ne' quali si tratta della natura, & bontà dell' acque, & specialmente del Teuere, & dell'acque antiche di Roma, del Nilo, del Pò, dell'Arno, & d'altri fonti, & fiumi del mondo. Dell'vso dell'acque, & del beuere in fresco, con neui, con ghiaccio & con salnitro. Delle inondationi, & de'rimedii, che gli antichi Romani fecero, & che hoggidi si possan fare in questa, & in ogni altra inondatione......In Venetia, MDLXXVI. 4to. (8)ff. 309 pp. *Gamba* (1220).

**Bakius [Bake]**, Ernst.

1. Q. B. V. D. Disputationem meteorologicarum primam de meteoris in genere......subjiciunt praeses M. Ernestus Bakius......& respondens Johannes Christiani Grim: Misn......Wittebergae 1654. 4to. (6) ff.
2. Q. B. V. D. Disputationem physicam de meteoris ignitis......subjiciunt praeses M. Ernestus Bakius & respondens Samuel Henkelius, Schönbec. Saxo......Wittebergae, literis Johannis Haken. Anno CIↃIↃCLVII. 4to. (12) ff.
3. Q. B. V. D. Disputationem physicam de meteoris aqueis......sistit eruditorum disquisitioni praeses M. Ernestus Bakius respondente M. Justo Hartranfft, Barbiens. Sax......Wittebergae, literis Johannis Haken. Anno MDCLVIII. 4to. (10) ff.
4. Q. B. V. D. Physicam disputationem, de meteoris spirituosis,......subjiciunt praeses M. Ernestus Bakius......& respondens Theodorus Schalitzius, Pombsensis Misnicus......Wittebergae typis Johannis Röhneri......Anno MDCLX. 4to. (10) ff.
5. Q. R. B. V. Physicam disputationem, de meteoris emphaticis, ...... sistunt praeses M. Ernestus Bakius ...... & respondens Adamus Popradius, Bela

**Bakius** [**Bake**], Ernst—Continued.

Hungarus ......Ex chalcographeo Johannis Borckardi. Anno 1660. 4to. (16) ff. *Hellmann* (584).

**Bacon**, Francis.

1. Francisci de Verulamio Historia naturalis et experimentalis de ventis etc. Lugd. Batav. Apud Franciscos Hegerum et Hackium. Anno 1638. Small 12mo. (14) ff. 340 pp. (16) ff. Engraved title.

   One of the smallest meteorological books I know; smaller than Mr. Symons' Pocket Altitude Tables, London, 1877.

2. Histoire des vents, ov il est traitté de leurs causes, & de leurs effets; composée par Messire François Bacon, Grand Chancelier d'Angleterre; et fidellement tradvitte par J. Bavdoin. A Paris. Chez Cardin Besongne...... MDCL...... Small 8vo. 10 pp. (3) ff. 222 pp. (1) f. Frontispiece.

   Scarce. *Brunet* (I 602). *Graesse* (I 272). *Lowndes* (I 93).

**Bartholinus**, Thomas and Erasmus.

1. Thomae Bartholini de nivis usu medico observationes varie. Accessit D. Erasmi Bartholini de figura nivis dissertatio; cum operum authoris catalogo. Hafniae, typis Matthiae Godicchii, sumptibus Petri Haubold, Bibl. CIↃIↃCLXI. Small 8vo. (24), 232, (14) 42, (16) pp. With a copper plate containing various forms of snow-crystals.

   Scarce. The first edition of E. Bartholinus' dissertation *de figura nivis* is said to have been published in 1660, but I have been unable to find a copy of this edition, which does not exist even in the Royal Library at Copenhagen. The preface is signed: *Hauniae, Anni MDCLX. Cal. Mart.*

2. Erasmi Bartholini de naturae mirabilibus qvaestiones academicae. Hafniae, sumptibus Petri Hauboldi......Anno CIↃIↃCLXXIV. 200 pp. (4) ff. 4to.

   Contains a reprint of the tract "de figura nivis," which also is here said to have been published in 1660.

**Bartholomaeus Anglicus.** [**de Glanvilla.**]

Liber de proprietatibus rer' Bartholomei Anglici Ordinis Minor'. Fol. (6) 320 ff. (last blank). [In fine:]......Impressus Argentine Anno Domini MDV......

Good and well printed edition of this famous encyclopaedic work. The eleventh book is devoted to meteorology. A pretty good analysis of the contents may be found in the modern book: Medieval Lore: an epitome of the science, geography, animal and plant folk-lore and myth of the middle age: being classified gleanings from the encyclopedia of Bartholomew Anglicus on the properties of things. Edited by Robert Steele......London, Elliot Stock 1893. 8vo. *Brunet* (III 1619). *Graesse* (III 91). *Lowndes* (II 898).

**Bartholomaeus de Usingen.**

Compendiū natural' phie opa et studio singulari M. Bartholomei de vsingen. In Gymnasio Erphurdiēsi collectum ad laudem dei et rei publice litterarie pfectū cui' lectione attenta naturalis scie cādidati facile prima physice capient elementa......4to. (62) ff. [In fine:] Impressum Erphordie per wolffgangum Schenken. [Without year, but probably about 1500.]

Very scarce. A treatise of (Aristotelean) natural philosophy, containing the meteorology, in use at the University of Erfurt. *Graesse* (I 302.)

**Bartoli**, Daniello (S. J.)

La tensione, e la pressione disputanti qual di loro sostenga l'argentovivo ne'cannelli dopo fattone il vuoto. Discorso del P. Daniello Bartoli della compagnia di Giesu. In Roma, MDCLXXVII. A spese di Nicolò Angelo Tinassi. 12mo. (2) ff. 284 pp. Two plates. Original edition. *Gamba* (1774.)

**Baudisius.**

Q. D. B. V. De lapide fulminari disputationem physicam......sub moderamine ......Dn. M. Simonis Friderici Frenzelii......proponit auctor Andreas Baudisius, Lignicio-Silesius ...... Anno CIↃIↃCLXVIII. Wittebergae, typis Matthaei Henckelii. 4to. (12) ff. *Hellmann* (21).

**Beda Venerabilis.**

Bedae presbyteri anglosaxonis viri ervditissimi, de natvra rervm et temporvm ratione libri dvo. Nunc recens inuenti, & in lucem editi......Basileae excvdebat Henricvs Petrvs mense Martio, An: MDXXIX......Fol. (16), 74 ff.

This seems to be the first separate edition of this work of the author; see Wright's Biographia Britannica Literaria, anglo-saxon period, p. 284. A good analysis of the meteorological conceptions of this famous scholar is to be found in "Beda der Ehrwürdige und seine Zeit. Von Dr. Karl Werner. Wien, W. Braumüller 1875. 8vo. viii, 235 pp. *Brunet* (I 731). *Graesse* (I 321). *Lowndes* (I 143).

**Benincasa,** Rutilio.

1. Almanacco perpetvo di Rvtilio Benincasa Cosentino, illustrato, e diuiso in cinque parti, e quelle in vinti trattati distinte......Da Ottavio Beltrano di Terra Nova di Calavria Citra.........In Ancona. Appresso il Beltrano. MDCLIII. 4to. (6)ff. 382 pp. (5)ff. Portrait of Beltrano on the back of the fifth fol. With woodcuts in the text.
2. [The same.] In Venetia. Per il Prodocimo. MDCLXXXXI......8vo. (12) ff. 316 pp., (1) f., 140 pp. Woodcuts.

The original edition of this Italian chap-book, which contains many meteorological chapters and an elaborate system of weather-foretelling based on the planets, was issued at Naples in 1593. *Riccardi* (114).

**Berger,** Valentin.

Actus oratorius de natura ventorum autore Valentino Bergero, Ohrdruvio-Thuringo. Impensis Martini Mülleri, Bibliopolae Numburg: Jenae. Typis Georgii Sengenvvaldi, Anno CIↃIↃCLVII. 12mo. (8) ff. 274 pp. Engraved title, with the inscription: Aeolus Dramaticus......*Hellmann* (29).

**Berigardus,** Claudius.

Circulus Pisanus Claudii Berigardi Molinensis olim in Pisano, iam in lyceo Patauino philosophi prim. de veteri et peripatetica philosophia in Aristotelis libros octos physicorum, quatuor de coelo, duos de ortu & interitu, quatuor de meteoris, & tres de anima......Opus in hac secunda editione auctius & retractatius. Patavii, MDCLXI. Typis Pauli Frambotti......4to. (9) ff. 729, (23) pp. Portrait of the author. Six parts in one volume. See the extensive note in *Libri* (968).

**Bianchi,** Pietro.

Pronostico et giudicio universale del presente anno 1572. Dell'eccellentis. astrologo maestro Pietro Bianchi da Luccioli discepolo di Nostr' Adamo. ...... In Venetia. Apresso Giouan Francesco Camotio. MDLXXI. 4to. (8) ff. with woodcuts.

**Bleidner,** Johann.

Disputatio physica de meteoro nivis, quam ...... sub praesidio Dn. M. Michaelis Marggraffens ..... examini ventilandam subjiciet Joh. Bleidner, Lobenst. Variscus ...... auctor et respondens ...... Anno Messiano CIↃIↃCLXVII. Lipsiae, e chalcographeo Samuelis Spörelii. 4to. (7) ff. *Hellmann* (587).

**Blancanus,** Josephus. [**Biancani,** Giuseppe.]

1. Aristotelis loca mathematica ex vniversis ipsius operibus collecta, & explicata. Aristotelicae videlicet expositionis complementum hactenus desideratum. Accessere de natura mathematicarum scientiarum tractatio; atque

**Blancanus,** Josephus. [**Biancani,** Giuseppe.]—Continued.
clarorum mathematicorum chronologia. Authore Iosepho Blancano Bononiensi è Societate Iesu ...... Bononiae MDCXV. Apud Bartholomaeum Cochium ...... 4to. 283, 65, (7) pp. Woodcuts.

Three parts, with separate titles, in one volume. Meteorology pp. 89–131.

2. Sphaera mundi, seu cosmographia demonstratiua, ac facili methodo tradita: in qua totius mundi fabrica, vna cum nouis, Tychonis, Kepleri, Galilaei, aliorvmq; astronomorum adinuentis continetur......Authore Iosepho Blancano Bonon. e Soc. Iesu......Mutinae, ex typographia Juliani Cassiani 1635. Fol. (6) ff. 232, 24 pp. (1) f. 1 table, 5 plates and many woodcuts in the text. Two parts in one volume.

Liber sextus: De Aere.—Describes the thermometer and says (on p. 55): "auxilio huius instrumenti quod ego thermoscopium libenter appellarem, multa ad aeris naturam spectantia, indagari possunt; audiui Doctorem quendam Medicum, Patauij degentem, qui Sautorius cognominatur huius esse inuentorem". *Riccardi* (127).

**Blemmidas,** Nicephorus.

1. Nicephori Blemmidae epitome physica. Triginta & unius gravissimorum capitū, cum fragmento......edidit Iohannes Wegelinus Augustanus...... Augustae Vindelicorum excudit Dauid Francus. Anno salutis MDCV. Small 8vo. (16) ff., 280 pp., (12) ff. The text is in Greek.
2. Nicephori Blemmidae epitome physica latine versa......& iam primum sic edita a Iohanne Wegelino Angustano......Augustae Vindelicorum, apud Davidem Francum. Anno MDCVI. Small 8vo. (8) ff., 404 pp. (10) ff. Latin translation.

Chapters 14 to 23 deal with meteorology. *Brunet* (iv 54 "Nicephorus"). *Graesse* (I 439).

**Bohun,** R.

A discourse concerning the origine and properties of wind. With an historicall account of hurricanes and other tempestuous winds. By R. Bohun, Fellow of New Coll: in Oxon. Oxford. Printed by W. Hall for Tho. Bowman. Anno Dom. 1671. Small 8vo. (11) ff. 302 pp.

**Bonatus,** Guido. [**Bonatti.**]

1. Registrum Guidonis Bonati de forliuio. [On fol. 15:] Guido bonatus de forliuio. Decem continens tractatus Astronomie. 4to. (422) ff. [In fine:] Erhardiq; ratdolt......Auguste vindelicorum......MCCCCLXXXXI.

Scarce original edition of a famous astrological work, the last part of which deals with astro-meteorology.

2. Gvidonis Bonati Foroliviensis mathematici de astronomia tractatvs x vniversum quod ad iudiciariam rationem natiuitatum, aëris, tempestatum attinet, comprehendentes. Adiectus est Cl. Ptolemaei liber fructus, cum commentarijs Georgij Trapezuntij. Basileae, Anno MDL. Fol. (8) ff. 848, 62 columns. *Brunet* (I 1089). *Graesse* (I 483). *Hain* (3461). *Riccardi* (148).

**Bonaventura,** Federico.

Federici Bonaventvrae Vrbinatis. Anemologiae pars prior, id est de affectionibvs, signis cavsisque ventorum ex Aristotele, Theophrasto, ac Ptolemeo tractatus......Vrbini. Apud Bartholomaeum & Simonem Ragusios fratres. MDLXXXXIII. 4to. (26) ff. 442 pp. (1) f. [blank].

Contains the latin translation of the meteorological works of Theophrastus, commentaries of the author on these works and similar extracts from Aristotle, Columella and Plinius. *Graesse* (I 485). *Riccardi* (151).

**Borelli**, Giovanni Alfonso.

1. Historia et meteorologia incendii Aetnaei anni 1669. Ioan. Alphonsi Borelli in academia Pisana matheseos professoris accessit responsio ad censuras Rev. P. Honorati Fabri contra librum auctoris de vi percussionis. Regio Ivlio, in officina Dominici Ferri 1670......4to (6) ff. 162 pp. (1) f. One fold. plate and woodcuts.
2. De motionibus naturalibus, a gravitate pendentibus. Lugduni Batavorum. Apud Petrum Van Der Aa. MDCLXXXVI. 4to. (2) ff. 360 pp. (16) ff. 14 fold. plates. Chapter v: De structura, gravitate, aequilibrio & vi elateria aeris. *Graesse* (I 495). *Riccardi* (158).

**Brerewood**, Edward.

Tractatvs qvidam logici de praedicabilibvs et praedicamentis ab eruditissimo Edvardo Brerewood......olim conscripti......Editio tertia, in qua accesserunt ejusdem authoris insignes tractatus; prior de meteoris......Oxoniae, excudebat Guilelmus Turner. MDCXXXVII. 8vo. (16) ff. 431 pp. (2) ff. 105, (3), 26 pp. With woodcuts. *Watt* (I 148t). *Lowndes* (I 262) mentions the edition of 1631.

**Caesius**, Georg.

Prognosticon astrologicum, oder teutsche Practica, von den vier Zeiten...... MDLXXX. Jars...... Durch M. Georgium Caesium zu Leutershausen. 4to. (12) ff.

The title of this "Practica" has been reproduced in facsimile in my book "Meteorologische Volksbücher" (p. 29). *Hellmann* (71).

**Camerarius**, Rudolph Jakob.

Ephemerides meteorologicae Tubingenses, ab anno seculi nonagesimo primo ad qvartum Rudolphi Jacobi Camerarii, phil. et med. d. et prof. acad. curios. Cum ill. D. Bernardini Ramazzini ephemeridibus barometricis Mutinensibus, anni MDCXCIV. Augustae Vindelicorum, impensis Krونigeri & Haeredum Goebelii......Anno MDCXCVI. 4to. 105 pp.

The earliest extant instrumental meteorological observations made in Germany. Professor Samuel Reyher began at Kiel a similar series of observations in or about 1678, but they are not preserved, except a short extract containing the lowest temperatures observed in the years from 1679 to 1709. *Hellmann* (72).

**Cardanus**, Hieronymus. [**Cardano**, Girolamo.]

1. Hieronimi C. Cardani medici Mediolanensis, practica arithmetica & mensurandi singularis...... [Portrait of the author]. Small 8vo. (304) ff. [In fine:] Anno......MDXXXIX. Io. Antonius Castellioneus......

   Very scarce. On the fol. with the signat. PPiiii: Anemographia, with a woodcut of the wind rose. *Brunet* (I 1572). *Graesse* (II 45). *Riccardi* (248).
2. Hieronymi Cardani Mediolanensis medici de svbtilitate libri xxi. Nvnc demum recogniti atq; perfecti......Basileae Per Lvdovicvm Lvcivm. Anno 1554. Fol. (12) ff. 561 pp. With woodcuts.

   Valuable work for the history of meteorology and terrestrial magnetism. The original edition was issued in 1550.
3. Hieronymi Cardani Mediolanensis medici de rervm varietate libri xvii...... Portrait of the author. Basileae, Anno MDLVII. Fol. (6) ff. 707 pp., (16) ff. With woodcuts.

   Original edition of this encyclopædic work.
4. Hieronymi Cardani .....commentarii in Hippocratis de aere, aqvis et locis opvs....Accedvnt praeterea......Joan. Baptistae Card. medici., D. Hier. Card. fil. de fulgure lib. unus......Basileae Ex officina Henricpetrina. Fol. (28) ff. 338, (2) pp. [In fine:]......Anno salvtis MDLXX. Woodcuts. The tract "de fulgure" from pp. 271 to 304.

**Casati**, Paolo, S. J.

Vacvvm proscriptvm. Dispvtatio physica avthore Pavlo Casato Placentino Societatis Iesv: in qua nvllvm esse in rervm natvra vacuum ostenditur; & potissimum examinatur, an ab argento vivo descendente in fistula superne clausa vacuum relinquatur. Huiusque experimenti symptomata explicantur. Genvae; imprimi curabit Joannes Dominicus Peri......MDCXLIX. 4to. (3) ff., 176 pp., (6) ff. With woodcuts. Scarce. *Riccardi* (270). *Watt* (I 199 r).

**Castelli**, Benedetto.

1. Della misura dell' acque correnti di D. Benedetto Castelli Abbate di S. Benedetto Aloysio, e matematico di Papa Urbano VIII, professore nello studio di Roma. In questa terza edizione accresciuta del secondo libro, e di molte curiose scritture non più stampate......In Bologna, per gli HH. del Dozza. MDCLX. Small 4to. (10) ff. 184 pp. Frontispiece and woodcuts. *Brunet* (I 1625). *Gamba* (1845). *Graesse* (II 64). *Riccardi* (289).

   Contains an account of the earliest measurement of rainfall, made in 1639 at Perugia, Italy.

2. Alcuni opuscoli filosofici del Padre Abbate D. Benedetto Castelli da Brescia......In Bologna, per Giacomo Monti, 1669. Small 4to. (4) ff. 77 pp.

   Deals with the intensity of solar radiation.

**Castrensis**, Stephanus Rodericus.

Stephani Roderici Castrensis Lvsitani medici, ac philosophi praestantissimi, et in Pisana schola medicinam primo loco docentis, de meteoris microcosmi libri quatuor. Cvm indice rervm, et verborvm. Florentiae, MDCXXI. Apud Iunctas......Fol. (6) ff. 229 pp. (8) ff.

A very curious book, treating of the "meteors" of the human body.

**Claramontius**, Scipio. [**Chiaramonti**, Scipione.]

Scipionis Claramontii Caesenatis in Aristotelem de iride, de corona, de pareliis, et virgis commentaria. Perillustri, et clarissimo viro D. D. Nicolao Foresto. Venetiis, MDCLXVIII. Apud Scipionem Banca......4to. (6) ff. 182 pp. With woodcuts. *Graesse* (II 133). *Riccardi* (App. I, 14).

**Cleomedes.**

Cleomedis meteora graece et latine. A Roberto Balforeo ex Ms. codice bibliothecae illustrissimi cardinalis Ioyosii multis mendis repurgata, latine versa, & perpetuo commentario illustrata......Bvrdigalae, apud Simonem Milangivm. 1605. 4to. (8) ff. 285, (9) pp. Woodcuts.

The best edition is that issued by J. Bake. Lugduni Batavorum. 1820. 8vo. xvi, 487 pp. *Brunet* (II 200). *Graesse* (II 200). *Watt* (I 221 i).

**Cock**, William.

Meteorologia oder der rechte Weg vorher zu wissen, zu beurtheilen die Veränderung der Lufft und Abwechselung des Wetters in verschiedenen Ländern. Darinnen auch entdecket worden die Ursachen, warum die gemeine Calender-Schreiber so sehr fehlen; und die rechte Weise das Wetter zu erkennen klar und deutlich erwiesen wird. Durch William Cock, Philomathem. Ein nützlich Werck für Schiffer, Gärtner, Landleute, Reisende, wie auch alle curiöse Untersucher der Natur und ins gemein vor alle und jede Personen, dergleichen bissher noch nicht zu finden. Aus der Engl. Sprach ins eutsche übersetzet. Hamburg 1691. Small 8vo. 55 pp.

Scarce. The original English work was issued at London in 1671. Cock's meteorological system was also propagated in Germany by the famous chemist G. E. Stahl (Einleitung zu der neuen Meteoroscopie, oder Witterungs-Deutung nach William Cock's Grund-Regeln. Halle 1716. 8vo.).

**Colerus**, Johannes.

[Calendarium oeconomicum et perpetuum.] 4to. 280 pp. (24) ff. [Title wanting; probably issued at Wittenberg in 1606.] M. Johannis Coleri ander Theil zum calendario perpetuo gehörig liber quodlibeticus genant. Darinen allerley sachen zusammen getragen......1606......Wittemberg, in vorlegung Paul Helwigs Buchführers daselbst. 4to. (16) ff. 44, 75 pp.

Replete with weather proverbs and weather folklore. The last 75 pp. "Ein elementisch vnd irdische Astrologia" contain a popular treatise on meteorology, relating especially to weather prognostics, being merely a reprint of the excessively scarce book of P. T. Flemlöse, printed at Uraniborg (Observatory of Tycho Brahe in the island Hveen) in 1591. The original edition of Colerus' Calendarium was published at Wittenberg in 1591. *Graesse* (II 213).' *Hellmann* (80).

**Collegium Conimbricense.** [College of Jesuits at Coimbra in Portugal.]

Commentarii Collegii Conimbricensis, Societatis Iesv, in libros meteororum Aristotelis Stagiritae......Coloniae, impensis Lazari Zetzneri. CIↃIↃC. Small 4to. (2) ff. 72 pp., with two columns, (4) ff.

**Contarenus**, Gaspar.

Gasparis Contareni cardinalis ...... de elementis & eorum mixtionibus libri quinque ...... Scipionis Capitij de principijs rerum poema ...... Lutetiæ Parisiorum per Nicolaum Diuitem ...... 1548. Small 8vo. (8), 119 ff.

**Cortes**, Jeronimo, de Valencia.

Lvnario perpetvo, y general, y pronostico de los tiempos vniversal y particular para cada reyno, y prouincia: al qual se han añadido muchas cosas notables ...... Todo reuisto y mejorado en esta tercera y ultima impressiõ por el mismo auctor Hieronimo Cortes, natural de Valencia ...... Impresso en Barcelona en casa di Ioã Amello ...... Año 1599. Small 8vo. (120) ff.

Original edit. issued in 1594 at Valencia. *Picatoste* (57). This book, which for his weather predictions has always been in great favor in Spain, is still reissued almost every year, and, as the "verdadero Zaragozano" (another similar work) sold in the streets and public places of the larger Spanish cities. Old editions are very scarce.

**Crusius**, Johann.

Diarium astrologicum & meteorologicum: oder grosse Practica, auff das Jahr ...... MDCXXXXI ...... Durch Johannem Crvsivm ...... Gedruckt zu Nürnberg, in Verlegung Wolffgang Endters. 4to. (16) ff.

**Cusa**, Nicolaus de.

D. Nicolai de Cvsa cardinalis, vtriusque iuris doctoris, in omnique philosophia incomparabilis viri opera. In quibus theologiae mysteria plurima, sine spiritu Dei inaccessa, iam aliquot seculis uelata & neglecta reuelantur. Praeterea nullus locorum communium theologiae non tractatur. Item in philosophia praesertim in mathematicis, difficultates multae quas ante hunc autorem (ceu humanae mentis captum excedentes) nemo prorsus aggredi fuit ausus, explicantur & demonstrantur. Postremo ex utroq; jure de maximis ciuilibus & ecclesiasticis rebus consilia & responsa dantur: et inextricabiles causae deciduntur. Librorum catalogum uersa pagina indicabit. Cum priuilegio Caes. Maiest. Basileae ex Officina Henricpetrina. Fol. (48) ff. 1176 pp. (2) ff. [In fine:] Basileae ex Officina Henricpetrina mense Augusto, Anno MDLXV.

As I have pointed out in my paper "Die Anfänge der meteorologischen Beobachtungen und Instrumente" (Himmel und Erde ii, 1890), Nicolaus de Cusa is the inventor of the first hygroscope; see page 176 of his work. *Brunet* (II 454). *Graesse* (II 313). *Watt* (I 278 *w*).

**D**** (Dalence).**

1. Traitté de l'aiman. Divisé en deux parties. La prémiére (sic!) contient les expériences; & la seconde les raisons que l'on en peut rendre. Par Mr. D***. A Amsterdam. Chez Henry Wetstein, 1687. 12mo. (10) ff. 140 pp. (4) ff. 33 plates and frontispiece.

   I possess another edition of this little and interesting treatise (Curieux traitté......Imprimé A Paris. En 1712).

2. Traittez des barometres, thermometres, et notiometres, ou hygrometres. Par Mr. D***. A Liege, Anno MDCXCI. Small 4to. (2) ff. 45, (3) pp., 35 plates and frontispiece.

   Fine second edition of the first special treatise on meteorological instruments, the *editio princeps* having been issued at Amsterdam in 1688 (12mo). I possess another edition in 8vo., issued at Amsterdam in 1707.

3. Neu-Erfundener mathematischer Curiositäten, erster Theil. Worinnen vermittels drey sonderbahrer Instrumenten, durch wunderbahre Würckung der Natur und Kunst, I. die Schwäre und Leichte, II. die Truckene und Feuchte, III. das Ab- und Zunehmen der Hitz und Kälte der Lufft zu erkennen seynd......Maintz, in Verlegung Ludwig Bourgeat......MDCXCVII. Small 8vo. 88 pp. 35 plates and frontispiece......Zweyter Theil. Worinnen vermittels sonderbahrer Würckung der Natur und Kunst, die Krafft und Eigenschafft des Magnets entdecket wird......Maintz. In Verlegung Ludwig Bourgeat......MDCXCVII. Small 8vo. 83, (5) ff. 33 plates and frontispiece.

   Second translation into German (first issued in 1688) of both treatises of Dalencé. I possess also the third edition of the same translation, issued by the same publisher at Maintz in 1701. The plates in the original French editions are better than those of the translation. I possess also a Dutch and an Italian translation of Dalencé's treatise on meteorological instruments, but both are issued after 1700 ('s Gravenhage, 1730; Venezia, 1753). An earlier German edition of the treatise on the magnet I possess, is this:

4. Magnetologia curiosa. Das ist gründtliche Abhandlung des Magneths, in zwey Abtheilungen enthalten..... ausz dem Frantzösischen in dasz Teutsche übersetztet durch I. C. H. M. D. Mäyntz, in Verlegung des Vbersetzers......1690. 4to. (2) ff. 50 pp. (1) f. 33 plates.

**Danti,** Pellegrino. [Maestro, or Padre **Egnazio.**]

Primo volume dell'vso et fabbrica dell'astrolabio, et del planisferio. Di Maestro Egnatio Danti publico lettore delle mathematiche nello studio di Bologna. Nuouamente ristampato, & accresciuto in molti luoghi, con l'aggivnta dell'vso, & fabbrica di noue altri istromenti astronomici, come nella faccia seguente si contiene......In Firenze, appresso i Giunti, 1578......4to. (8) ff. 325, (3) pp. With woodcuts in the text.

Contains on pp. 251 to 281 "Anemografia di Maestro Egnatio Danti, dell'ordine di San Domenico. In dichiarazione dello anemoscopio, instrumento mostratore de'venti: Tradotto di latino in vulgare, da M. Pietroantonio Cattani, Al Mag. M. Lorenzo Costa." For details see my paper "Die Anfänge der meteorologischen Beobachtungen und Instrumente" (p. 11). *Brunet* (II 519). *Gamba* (1342). *Graesse* (II 334). *Riccardi* (388). *Watt* (I 284 *t*).

**Descartes,** René.

Renati Des-Cartes principia philosophiae. Amstelodami, apud Johannem Jansonium Juniorem, Anno MDCLVI. 4to. (17) ff. 241 pp. Portrait of the author and many woodcuts.

Renati Des Cartes specimina phiosophiae sev dissertatio de methodo recte regendae rationis, & veritatis in scientiis investigandae: dioptrice, et

**Descartes**, René—Continued.

meteora. Ex Gallico translata, & ab auctore perlecta, variisque in locis emendata. Amstelodami, apud Johannem Janssonium Juniorem, Anno MDCLVI. 4to. (8) ff. 290 pp. With many woodcuts in the text.

"Meteora" pp. 181 to 290. The original edition in French was published in 1637. *Brunet* (II 608). *Graesse* (II 364). *Watt* (I 197x).

**Dingley**, Robert.

Vox coeli; or, philosophical, historicall, and theological observations of thunder. With a more general view of God's wonderful works. First grounded on Job 26. 14., but now enlarged into this treatise. By Robert Dingley, M. A,, once Fellow of Magdalen Colledge in Oxford; now minister of God's word at Brixton in the Isle of Wight, and county of Sovthampton...... London, Printed by M. S. for Henry Gripps......1658. Small 8vo. (20) ff. 174 pp. *Watt* (I 305 b).

**Dobrzenski**, Jacob J. W., de Nigro Ponte.

Nova et amaenior de admirando fontivm genio (ex abditis natvrae clavstris, in orbis lvcem emanante) philosophia.......avctore Iacobi I. W. Dobrzenski de Nigro Ponte Boemo Pragensi. P. E. M. D. Opvscvlvm......Ferrariae CIƆIƆCLVII. Apud Alphonsum & Io. Baptistam de Marestis......Fol. (14) ff. 121 pp. (1) f. Fine frontispiece with another title before the printed one. Many figures in the text. *Brunet* (II 779). *Graesse* (II 414). *Watt* (I 308 n). Deals with rainfall.

**Drebbel**, Cornelius.

Ein kurtzer Tractat von der Natur der Elementen vnd wie sie den Windt, Regen, Blitz vnd Donner verursachen, vnd wozu sie nützen. Durch Cornelium Drebbel in Niederländisch geschrieben, vnd allen der Natur liebhabern zu nutz in Hochdeutsch getrewlich vbergesetzt. Gedruckt zu Hamburg, bey Paul Langen, Im Jahr 1619. Small 8vo. 30 pp.

Scarce. Contains nothing to justify the supposition that Drebbel invented the thermometer. *Graesse* (II 433). *Bierens de Haan*: Bibliographie Néerlandaise Historico-Scientifique......in Boncompagni's Bulletino di bibliographia e di storia delle scienze matematiche e fisiche. Tomo xiv. Roma, 1881.

**Du Hamel**, Jean Baptiste.

Ioan. Bapt. Dv Hamel de meteoris et fossilibvs libri dvo. In priore libro mixta imperfecta, quaeque in sublimi aëre vel gignuntur, vel apparent, fuse pertractantur. Posterior liber mixta perfecta complectitur; vbi salium, bituminum, lapidum, gemmarum, & metallorum naturae, causae, & vsus inquiruntur. Parisiis, apud Petrum Lamy......MDCLX......4to (14) ff. 310 pp. (3) ff. With woodcuts.

**Elephantutius**, Joannes. [**Fantuzzi**, Giovanni.]

Eversio demonstrationis ocvlaris loci sine locato, &c. pro vacuo imaginario dando in fistula vitrea mercurio in ea descendente. Ab admod. R. P. F. Valeriano Magno editae. Ioannis Elephantutij Bonon......Bononiae, Typis haeredis Victorij Benatij, 1648......4to. (2) ff. 48, 24 pp.

See remarks under "Petit." *Riccardi* (446).

**Eliacus**, Petrus de. [**Aliacus**, Pierre **d'Ailly**.]

Tractatus Petri de Eliaco epi Cameracensis: sup libros metheororũ: de impressionibus aeris. Ac de hijs quae in prima: secunda: atq; tertia regionibus aeris fiunt. sicut sunt sydera cadentia: stellae: comatae: pluuia: ros: pruina: nix: grando: ventus: terremotus, deq; generatis infra terram. Small 4to. (1), xxvi ff. [In fine:] Impressum a Johanne Priis Argentinae in aedibus Thiergarten. Anno MCCCCCIIII.

Scarce treatise on meteorology, which has been issued 5 or 6 times.

**Faber**, Jacobus, Stapulensis. [**Le Fevre d'Estaples**, Jacques.]

Meteorologia Aristotelis eleganti Iacobi Fabri Stapulensis paraphrasi explanata. Cōmentarioq; Ioannis Coclaei Norici declarata ad foelices in philosophiae studiis successus calcographiae iam primū demandata. [Emblematic woodcut.] Chelidonius Musophilus. Ad Lectorem [a poem of 10 lines follows]. 8vo. XCIIII, (5) ff. [In fine, before the index :]...... Impressa Noribergae. In officina Friderici Peypusz. Anno salutis. MCCCCCXII...... With woodcuts. Scarce.

**Finaeus**, Orontius. (**Fine**, Oronce.)

Sphaera mvndi sive cosmographia qvinque libris recens auctis & emēdatis absoluta: in qua tum prima astronomiae pars, tum geographie, ac hydrographie, rudimenta pertractātur. Avthore Orontio Finaeo Delphinate, regio mathematicarum Lutetiae professore. Lvtetiae Parisiorvm, apud Michaëlem Vascosanum, uia Iacobea ad insigne fontis. MDLII......Small 4to. (6), 60 ff.

With several chapters on the atmosphere and on the winds; on fol. 58*b* a fine woodcut of a wind-rose in black and red. Third edition, the first being issued at Paris in 1542. *Brunet* (II 1260). *Graesse* (II 580).

**Fincelius**, Jobus.

Wunderzeichē. Warhafftige Beschreibung vnd gründlich verzeichnus schrecklicher Wunderzeichen vnd geschichten, die von dem Jar an MDXVII. bis auff jetziges Jar MDLVI. geschehen vnd ergangen sind nach der Jarzal. Durch Jobum Fincelium .....Gedruckt zu Franckfurt am Mayn, durch Thomam Rebart. Anno MDLXVI. Small 8vo. (176) ff.

Der ander teil. Wunderzeichen. Gründtliche verzeichnis schrecklicher Wunderzeichen vnd Geschichten, so jnnerhalb 40. Jaren sich begeben haben...... Durch Jobum Fincelium......Gedruckt zu Franckfurt am Mayn durch Thomam Rebart. Anno MDLXVI. Small 8vo. (192) ff.

Der dritte theil Wunderzeychen. Gründtliche Verzeichnusz, schrecklicher Wunderzeychen...... Durch Jobum Fincelium. Gedruckt zu Frankfurdt am Mayn, bey Weggand Hanen Erben. MDLXVII. Small 8vo. (252) ff.

Complete copies are very rare. There seems to exist an earlier edition, at least of the first part, printed at Nürnberg in 1556, for I find such a copy registered in the Catalogue of the Crawford Library of the Royal Observatory, Edinburgh, p. 95. The book is replete with accounts of extraordinary meteorological and other phenomena: optical phenomena, aurora borealis, inundations, hard winters, hot summers, storms, etc. *Hellmann* (129).

**Firmicus Maternus**, Julius.

Jvlii Firmici Materni Ivnioris Sicvli V. C. ad Mavortium Lollianum, astronomicōn libri viii, per Nicolavm Prvcknervm astrologum nuper ab innumeris mendis uindicati. His accesservnt Clavdii Ptolemaei......'αποτελεσμάτων quod quadripartitum uocant, lib. IIII; De inerrantium stellarum significationibus, lib. I; Centiloquium eiusdem. Ex Arabibus et Chaldaeis. Hermetis...... centum aphorism. lib. I. Bethem centiloquium. Eivsdem de horis planetarum liber alius. Almanzoris astrologi propositiones ad Saracenorum regem. Zahelis Arabis de electionibus lib. I. Messahalah de ratione circuli & stellarum, & qualiter in hoc seculo operentur, lib. I. Omar de natiuitatibus lib. III. Marci Manilii poetae disertissimi astronomicōn lib. V. Postremo Othonis Brvnfelsii de diffinitionibus & terminis astrologiae libellus isagogicus. Basileae. Per Ioannem Hervagivm. Anno MDLI. Mense Aprili. Fol. (6) ff. 244, 227 pp.

Scarce collection of old Greek, Roman, and Arabian astrological tracts, dealing also with astro-meteorology. The first edition was issued by the same publisher in 1538. *Brunet* (II 1270). *Graesse* (II 585).

**Firminus** (Firmin de Belleval).

1. Opusculū repertorii pronosticon in mutationes aeris tam via astrologica q; metheorologica vti sapiētes experientia comperientes voluerunt pq; vtilissime ordinatū incipit sīdere felici r primo prohemiū. 4to. (1) 49 ff., first blank. [In fine:]......Impressus est arte ac diligentia mira Erhardi Ratdolt de Augusta imperante inclyto Johanne Mocenico duce Uenetorū: Anno salutifere incarnationis. 1485. Uenetijs.

   Probably the earliest printed collection of weather predictions. Scarce. For the author see Symons' Monthly Meteorological Magazine, vol. xxvii. London, 1892, pp. 6, 36, and 176. *Brunet* (iv 903 "Prognosticon"). *Graesse* (v 457 "Prognosticon"). *Hain* (iv Nr. 13393).

2. Firmini repertorium de mutatione aeris, tam via astrologica, quam metheorologica, pristino nitori restitutum, per Philippum Iollainum Blereium, cum scholijs eiusdem. Parisiis. Apvd Jacobvm Kerver..... MDXXXIX. Small fol. (4). 79 ff. As scarce as the original edition.

**Fleischer**, Johann.

De iridibvs doctrina Aristotelis et Vitellionis, certa methodo comprehensa, explicata, & tam necessarijs demonstrationibus, quam physicis & opticis causis aucta à Iohanne Fleischero Vratislauiense. Praemissa svnt svccincto ordine ea optica, quorum cognitio ad doctrinam cum iridum, tum aliorum μετεώρων ι κατ' ἔμφασιν est necessaria. Wittebergae excvdebat Johannes Crato. Anno MDLXXI. Small 8vo. 8ff. 235, (5) pp. With many woodcuts.

Dedication copy of the author to his friend David Rhenisch. *Hellmann* (132).

**Fludd**, Robert, alias de Fluctibus.

1. Utriusque cosmi maioris scilicet et minoris metaphysica, physica atqve technica historia in duo volumina secundum cosmi differentiam diuisa. Avthore Roberto Flud alias de Fluctibus, Armigero, & in medicina Doctore Oxoniensi. Tomus Primus. De Macrocosmi historia in duos tractatus diuisa......Oppenhemii. Aere Johan-Theodori de Bry. Typis Hieronymi Galleri. Anno CIↃIↃCXVII. Fol. (1) f. 206 pp. 3 (ff), 788 pp., (5) ff. With many plates and woodcuts. The second part (with separate title: Tractatus secundus de natvræ simia seu technica macrocosmi historia inpartes undecim divisa) was issued in 1618, and contains on pp. 687–700 a chapter "De prognosticatione tempestatum".

2. Philosophia Moysaica. In qua sapientia & scientia creationis......explicatur. Avthore Rob. Flvd, alias De Flvctibvs ...... Govdae, excudebat Petrus Rammazenius, Bibliopola. Anno MDCXXXVIII. Fol. (4), 152 ff. With many figures.

   Description and figures of thermometers ("speculum calendarium") which are said to be 500 years old: "& agnosco me illud (vizard instrumentum) in veteri quingentorum saltem annorum antiquitatis manuscripto graphice specificatum, atque geometrice delineatum invenisse". (Fol. 1 verso.) *Graesse* (II 607). *Watt* (I 374).

**Fournier**, Georges.

Hydrographie contenant la theorie et la pratique de tovtes les parties de la navigation. Composé par le Pere Georges Fovrnier de la compagnie de Jesvs. Seconde edition. Reueuë, corrigée & augmentée par l'autheur auant son deceds. Plus, la nauigation du Roy d'Escosse Iaqves Cinqviesme du nom, autour de son royaume, & isles Hebrides & Orchades, sous la conduite d'Alexandre Lyndsay excellent pilote escossois. A Paris, Chez Iean dv Pvis, ruë Saint Iacqves. MDCLXVII......... Fol. (11) ff., 706 pp., (12) ff. [last blank].

**Fournier**, Georges—Continued.

Valuable and esteemed work. The eleventh book deals with the mariner's compass and the fifteenth with winds and storms. *Graesse* (II 622).

**Francisci**, Erasmus.

Der Wunder-reiche Uberzug unserer Nider-Welt oder Erd-umgebende Lufft-Kreys, nach seinem natürlichen Wesen, manchfaltigen Eigenschafften, Nutzen und Würckungen, natür-und unnatürlichen, feuer-und wässerigen Erscheinungen, (als da sind die Wasser-Sonnen, Regenbögen, Nacht-und Meer-Lichter, etc., Lufft-Wunder, Wolcken, Regen, Schnee ......... ) in unterschiedlichen Discursen abgehandelt......... Durch Erasmum Francisci. Nürnberg, In Verlegung Wolffgang Moritz Endter...... Anno MDCLXXX. 4to. (9) ff. 1450 pp. (15) ff. Frontispiece and plates.

An extremely curious stout volume, containing many interesting facts. *Graesse* (II 626). *Hellmann* (134).

**Fromondus**, Libertus. [**Froidmont**].

Liberti Fromondi S. Th. L. collegii Falconis in academia Lovaniensi philosophiae professoris primarii meteorologicorum libri sex. Cui accessit in hac ultima editione Thomae Fieni, & Lib. Fromondi dissertationes de cometa anni CIↃIↃCXVIII et clarorum virorum judicia de pluvia purpurea Bruxellensi. Londini, typis E. Tyler 1656. Small 8vo. (8) ff. (first blank) 505 pp. (15) ff. 147 pp.

The first edition was issued in Antwerp in 1627.

**Frytschius**, Marcus.

1. Meteororvm, hoc est, impressionvm aerearvm et mirabilium naturae operum, loci ferè omnes, methodo dialectica conscripti, & singulari quadam cura diligentiaq; in eum ordinem digesti ac distributi, a M. Marco Frytschio Lavbano Hexapolensi: Lusaciae superioris alumno. Item: Catalogvs prodigiorvm atque ostentorum, tam coelo quam in terra, in poenam scelerum ac magnarum in mundo vicissitudinum significationem, iam inde ab initio diuinitus exhibitorum, ab eodem conscriptus. Noribergae. Cum priuilegio regio ad decennium. [In fine:] Noribergae, in officina Ioannis Montani, & Vlrici Neuber. Anno MDLV. Small 8vo. (28), 179, (61) ff.

   Scarce original edition.

2. Meteororvm hoc est impraessionvm aerearvm et mirabilium naturae operum, loci fere omnes, methodo dialectica conscripti & singulari quadam cura ac diligentia in eum ordinem digesti & distributi a M. Marco Frytschio Lavbano, & nunc pluribus in locis aucti & emendati a M. Iohanne Hagio. Wittebergae. In officina Ioannis Lufftij. MDLXXXI. Small 8vo. (16) 182 ff.

3. De meteoris sive impressionibvs aereis loci methodo dialectica digesti ac distributi a M. Marco Frytschio Laubano: nvnc vero plvribus in locis auctiores & emendatiores, opera M. Johannis Hagij. Wittebergae. Excudebut Johannes Lufft, Anno MDLXXXIII. Small 8vo. (20), 182 ff.

**Garcaeus**, Johannes. [**Gartze.**]

Meteorologia conscripta a Iohanne Garcaeo pastore ecclesiae Dei in noua arce Brennonis. Additae svnt tabellae qvae totam meteororum doctrinam complectuntur, et exempla historica sacra & prophana, multorum seculorum, quibus haec materia scholasticorum causa illustrata est. Wittebergae. Anno MDLXVIII. Small 8vo. (19), 468 ff. 5 fold. tables.

Second edition of a very complete treatise on meteorology, the first having been issued in 1565. Scarce. *Hellmann* (144).

**Gemma**, Cornelius.

De natvrae divinis characterismis; sev raris & admirandis spectaculis, causis, indiciis, proprietatibus rerum in partibus singulis vniuersi, libri ii. Avctore D. Corn. Gemma, Louaniensi, regio medicinae professore...... Antverpiae. Ex officina Cristophori Plantini. MDLXXV. Small 8vo. 239 pp. Woodcuts.

Cornelii Gemmae......de natvrae divinis characterismis.....tomvs secvndvs quem Janvm trifrontem placuit appellari. Antverpiae. Ex officina Christophori Plantini......MDLXXV. Small 8vo. 287 pp. (16) ff. Woodcuts.

Contains a great many extraordinary weather phenomena, as inundations, heavy rains, intense frost, aurora borealis (with figures), and so on. *Bierens de Haan* (p. 615).

**Gilbert**, Guilelmus. [**William Gilbert** of Colchester.]

1. Guilielmi Gilberti Colcestrensis, medici Londinensis, de magnete, magneticisque corporibus, et de magno magnete tellure; physiologia noua, plurimis & argumentis, & experimentis demonstrata. Londini. Excudebat Petrus Short. Anno MDC. Fol. (8) ff. 249 pp. With many figures in the text and one fold. plate.

   Scarce original edition of this fundamental work on terrestrial magnetism. A facsimile reproduction was issued at Berlin by Messrs. Mayer & Müller, booksellers, in 1892.

2. Tractatus, sive physiologia nova de magnete, magneticisq; corporibus & magno magnete tellure, sex libris comprehensus, a Guilielmo Gilberto Colcestrensi, medico Londinensi. In quibus ea, quae ad hanc materiam spectant, plurimis & argumentis & experimentis exactissime absolutissimeq; tractantur & explicantur. Omnia nunc diligenter recognita, & emendatius quam ante in lucem edita, aucta & figuris illustrata, opera & studio D. Wolfgangi Lochmans, I. U. D. & mathematici. Ad calcem libri adiunctus est index capitum, rerum & verborum locupletissimus, qui in priore aeditione desiderabatur. Sedini, Typis Gotzianis. Anno MDCXXXIII. 4to. (10) ff. 232 pp. (17) ff. With many woodcuts in the text and 12 small plates.

   As scarce as the original edition. Assessor Lochmans published a previous one in 1628. A modern translation into English of Gilbert's standard work (original edition) by Mr. P. Fleury Mottelay was published by Messrs. John Wiley & Sons, New York, in 1893. *Brunet* (II 1592). *Graesse* (III 82). *Lowndes* (II 890). *Watt* (I 414).

3. Guilelmi Gilberti Colcestrensis, medici regii, de mundo nostro sublunari philosophia nova. Opus posthumum, ab authoris fratre collectum pridem & dispositum, nunc ex duobus MSS. codicibus editum. Ex museio viri perillustris Guilelmi Boswelli Equitis aurati &c.. & oratoris apud foederatos Belgos Angli. Amstelodami, apud LudovicumE lzevirium, CIƆIƆCLI. 4to. (7) ff., 316 pp., (2) ff.

   Deals chiefly with meteorology. Scarce.

**Glareanus**, Henricus. (**Loriti** of Glarus in Switzerland.)

Henrici Glareani Helvetii, poetae lavreati de geographia liber vnvs, ab ipso avthore iam tertio recognitvs. Apud Fribvrgvm Brisgoiae, An. MDXXXIII. 4to. 35, (1) ff. With figures in the text.

Earliest book—original edition issued at Basel in 1527—which mentions the declination or variation of the compass (fol. 9 verso). Scarce. *Brunet* (II 1623). *Graesse* (III 93).

**Goetz**, Johann Georg.

Prognosis astronomica, das ist: von natür-und vermuhtlicher Eigenschafft der Witterung......Auff das Jahr......MDCLXIII. Durch Joannem Georgium Götzn, Carinthum......Nürnberg. In Verlegung Christophori und Pauli Endtern. 4to. (16) ff.

**Gouye**, Thomas.

Observations physiques et mathematiques, povr servir à l'histoire natvrelle & à la perfection de l'astronomie & de la géographie: envoyées des Indes et de la Chine à l'Académie Royale des Sciences à Paris, par les Pères Jesuites. Avec les reflexions de Mrs. de l'Académie & les notes du P. Goüye, de la Compagnie de Jesus. A Paris, de l'imprimerie royale. MDCXCII. 4to. (2) ff. 113, 20 pp. With two maps.

Contains meteorological and magnetical observations.

**Gozze**, Nicolo Vito di. (From Ragusa, 2nd half of the 16th century).

Discorsi di M. Nicolo Vito di Gozze, gentil'hvomo Ragvgeo, dell'accademia degli occulti, sopra le metheore d'Aristotele, ridotti in dialogo & diuisi in quattro giornate...... In Venetia, MDLXXXIIII. Appresso Francesco Ziletti. 4to. (12), 147, (1) ff. With woodcuts. *Riccardi* (615). Scarce.

**Grandamicus**, Jacobus. [**Grandami**, Jacques.]

Nova demonstratio immobilitatis terrae petita ex virtvte magnetica. Et quaedam alia ad effectus & leges magneticas, vsumque longitudinum & vniversam geographiam spectantia, de nouo inuenta. Autore P. Iacobo Grandamico, è Societate Iesv. Flexiae. Apud Georgivm Griveav......MDCXLV. 4to. (4) ff. 170 pp. 3 plates, frontispiece, and many figures in the text.

Scarce book, and curious for the history of terrestrial magnetism.

**Gratarolus**, Gulielmus.

Mvndi constitvtionvm et tempestatvm praedictiones certae ac perpetvae, postremo editae: per Gvlielmvm Gratarolvm Bergomatem medicum physicum. Basileae per Petrvm Pernam. MDLVIII. Small 8vo. 77 pp. (1) f. (blank).

A scarce collection of weather signs or weather predictions arranged alphabetically.

**Grimaldi**, Francesco Maria, S. J.

Physico-Mathesis de lvmine, coloribvs, et iride, aliisqve adnexis libri dvo. In quorum primo afferuntur noua experimenta, & rationes ab ijs deductae pro substantialitate luminis. In secundo autem dissoluuntur argumenta in primo adducta, & probabiliter sustineri posse docetur sententia peripatetica de accidentalitate luminis......Avctore P. Francisco Maria Grimaldo Societatis Iesv. Opvs posthvmvm. Bononiae. MDCLXV. Ex typographia haeredis Victorij Benatij. 4to. (11) ff. 535 pp. (8) ff. Frontispiece and many woodcuts.

Scarce. *Brunet* (II 1740). *Riccardi* (630).

**Grotius**, Hugo. [**de Groot.**]

Hvg. Grotii Batavi syntagma Arateorvm opvs poeticae et astronomiae stvdiosis vtilissimvm: quo quae contineantur versa pagella indicabit. Ex officina Plantiniana, apud Christophorvm Raphelengivm......CIↃIↃC. Small 4to. (6) ff. 42, 36, 94, 24, 128 pp. With many large woodcuts and two plates.

Scarce. Esteemed commentary of Aratus' phenomena and prognostics. *Brunet* (II 1765). *Graesse* (III 162).

**Guericke**, Otto von.

Ottonis de Guericke Experimenta nova (ut vocantur) Magdeburgica de vacuo spatio primum a R. P. Gaspare Schotto .....nunc vero ab ipso auctore perfectius edita, variisque aliis experimentis aucta. Quibus accesserunt simul certa quaedam de aeris pondere circa terram ...... Amstelodami, Apud Joannem Janssonium à Waesberge, Anno 1672. Fol. (8) ff. 244 pp. (3) ff. With a large portrait of the author and many plates and figures.

Scarce and important work for the history of meteorology and terrestrial magnetism. *Graesse* (III 171). *Hellmann* (169).

**Gyraldus**, Lilius Gregorius. [**Giraldi**, Giglio Gregorio].

Lilii Gregorii Gyraldi Ferrariensis, de re nautica libellus, admiranda quadam & recondita eruditione refertus, nunc primum & natus & aeditus ..... Basileae, apud Mich. Isingrinium, MDXL. Small 8vo. 3 ff., 306 pp.

Deals also with the mariner's compass and with weather signs. *Riccardi* (605).

**Hartmann**, Georg.

Perspectiva commvnis. Ideo sic dicta, quod contineat elementa τῆς ὀπτικῆς, omnibus philosophiae studiosis necessaria...... Summa cura & diligentia emendata......per Georgium Hartmannum Norimbergensem. Norimbergae apud Iohan. Petreium. Anno MDXLII. 4to. (55) ff.

Scarce. An edition of John Peckham's treatise on perspective; deals also with the rainbow. *Hellmann* (181).

**Hauenreuter**, Johann Ludwig. [**Hawenreuter.**]

Commentarii Ioannis Lvdovici Havenrevteri med. doctoris, professoris et archiatri Argentinensis in Aristotelis philosophorum principis meteorologicorum libros quatuor..... Francofvrti, e collegio musarum Paltheniano MDCV. 8vo. (8) ff. 527 pp. Woodcuts.

Contains the Greek text of Aristotle, the Latin translation and the prolix commentaries of the author. *Hellmann* (183).

**Henisch**, Georg.

Georgii Henischii B. medici et mathematici Avg. commentarius in sphaeram Procli Diadochi: cui adiunctus est computus ecclesiasticus, cum calendario triplici, & prognostico tempestatum ex ortu & occasu stellarum. Avgvstae Vindelicorvm, Typis Davidis Franci. Anno MDCIX. 4to. (4) ff., 367 pp., (10) ff. 2 fold. tables. *Hellmann* (194).

**Heron** [Ctesibius].

1. Heronis Alexandrini spiritalivm liber. A Federico Commandino Vrbinate ex graeco, nvper in latinvm conversvs...... Vrbini MDLXXV. 4to. (2) 80 ff. Numerous woodcuts. Another edition, with the addition of J. P. Aleotti's "Quatuor theoremata spiritalia" Amstelodami. Apud Janssonio-Waesbergios MDCLXXX. 4to. (2) ff. 120 pp. Many woodcuts.
2. Gli artifitiosi et cvriosi moti spiritali di Herrone. Tradotti da M. Gio. Battista Aleotti d'Argenta......In Ferrara. MDLXXXIX. Per Vittorio Baldini ......4to. (6) ff. 103 pp. Many woodcuts. Another edition: In Bologna, MDCXLVII. Per Carlo Zenero. 4to. (4) ff. 84 pp.
3. Spiritali di Herone Alessandino ridotti in lingua volgare da Alessandro Giorgi da Vrbino......In Vrbino. Appresso Bartholomeo, e Simone Ragusij fratelli......1592. 4to. (4), 82 ff. Many woodcuts.

*Brunet* (III 129). *Graesse* (III 258); see also the articles *Commandino*, *Giorgi* and *Aleotti* in *Riccardi's* Biblioteca matematica italiana.

**Hobbes**, Thomas.

Dialogus physicvs de natvra aeris conjectura sumpta ab experimentis nuper Londini habitis in Collegio Greshamensi. Item de duplicatione cubi. (Londini 1661). 4to. 42 pp. 1 pl.

Bound together with other mathematical and philosophical tracts of the author into one volume, but wanting a general title. *Watt* (I, 501 *x*) mentions two editions: Lond. 1661 and Amst. 1668.

**Hoen**, Theodorus.

Natuerlycke Astrology; dat is de verthooninge, van de Aert, Natuer, ende kracht der Planeten, Aspecten met haer werckinge in's Menschen Lichaem. Door Theodorum Hoen, Landt-meeter Ingenieur en Astronomus in Leeuwarden. Tot Leeuwarden. By Gysbert Sybes......Anno 1659. Small 8vo. (10) ff. 220 pp.

The second part ("Natuerlijcke Astrologye," pp. 109 to 167) deals with weather prognostics. Scarce. *Bierens de Haan.*

**Honorius Augustudunensis.**

Mvndi synopsis: siue, de imagine mvndi: libri tres. Ab Honorio Solitario Avgvstvdvnense ante annos quadringentos sexaginta tres scripti, quorum tertius hactenus nunquam visus, iam vero vna cum duobus prioribus ex vetusto manuscripto codice primum in gratiam studiosorum luce donatus, prodit. Spirae .....apud Bernardum Albinum. Anno CIↃIↃLXXXIII. 12mo. (6) ff. 184 pp., (22) ff.

About this cosmographical work see my book "Meteorologische Volksbücher" (p. 14). *Graesse* (III 343).

**Hooke,** Robert.

Micrographia: or some physiological descriptions of minute bodies made by magnifying glasses with observations and inquiries thereupon. By R. Hooke, Fellow of the Royal Society.........London, printed for John Martyn .........MDCLXVII. Fol. (17) ff. 246 pp. (5) ff. 38 fold. plates.

New (Title) edition of the original one, issued in 1665. Contains the description of his wheel-barometer and figures of snow-crystals. *Brunet* (III 300). *Graesse* (III 344). *Lowndes* (II 1106). *Watt* (I 511).

**Hosmann,** Abraham.

1. De tonitru & tempestate, das ist: Nohtwendiger Bericht, von Donnern vnd Hagel-Wettern, wannen vnd woher sich dieselben verursachen, ob sie natürlich: Item ob Teufel vnd Zauberer auch Wetter machen können, durch was mittel sie gestillet vnd abgewendet werden, auch was man sich dabey zu erinnern, vnd in grossen Vngewittern zu trösten hat, so wol, was von denen zu halten sey, so durch solche vngestüme Wetter vmb jhr Leben kommen.........durch Abrahamum Hosmanum Laubanensem Lusatium Historicum, &c. Gedruckt zu Leipzig. In verlegung Henning Grossn des ältern.........Im MDCXII Jahr. 4to. 123 pp.
2. [The same title.] Jtzo vom Autore selbst vbersehen corrigiret vermehret vnd gebessert. Zu Magdeburg bey Johann Francken. Im MDCXVIII Jahr. 4to. 127 pp. *Hellmann* (212).

**Husch,** Johann.

Meteora rationibus, & experimentiis physicis illustrata.... .Anno MDCXC ..... publice propugnabit......Joann. Georgius Husch, Palatinus Schwandorffensis ......praeside R. P. Gabriele Hevenesi e Soc. Jesu......Viennae, Typis Joan. Jacobi Mann. 1690. 12mo. (4) ff. 240 pp. (8) ff. Engraved frontispiece.

**Ingegneri,** Carlo Guglielmo.

Meteorologia overo vaticinij perpetui della mutatione de' tempi, & d'altri accidenti del mondo. Dedotti dalle varie impressioni dell'aere. Dalle diuerse apparenze del cielo. Dalle proprietà naturali, & occulte dell'acque, e della terra. Da corpi perfetti, imperfetti, e misti, che si generano in esse. Distinti in qvattro libri. Ne'quali con breue, e risoluto metodo si toccano, non solo tutte le materie spettanti alle meteore, con dottrine per lo più diuerse dall' antichità, ma si dilucidano le qualità piu essentiali, e curiose de corpi celesti. Del Dottore Carlo Gvglielmo Ingegneri. All'eminentissimo, e reuerendissimo Sig., e Patron. Col. il Sig. Gio. Gerolamo Cardinale Lomellino Legato di Bologna. In Milano, MDCLVII. Appresso Lodouico Monza......Small 8vo. (11) ff. 334 pp. (9) ff.

**Isidorus Hispalensis.**

Isidori Hispalensis episcopi originum libri viginti ex antiquitate eruti et Martiani Capellae de nuptijs Philologiae & Mercurij libri nouem. Vterque, praeter Fulgentium & veteres grammaticos, varijs lectionibus & scholijs illustratus opera atq; industria Bonaventvrae Vvlcanii Brvgensis ...... Basileae, per Petrvm Pernam. (1577.) Fol. (6) ff. 225 pp., with two columns. (16) ff., 120 pp., with two columns. (2) ff.

Encyclopaedic work of natural sciences, geography, and so on. *Brunet* (III 463). *Graesse* (III 432).

**Jenisch**, Paul.

Christlicher vnd notwendiger vnterricht von Wettern, wann vnd woher sie sich vrsachen, wesz man sich dabey zu erinnern, wie man sich bey grossem Vngewitter trösten, vnd dieselben abwenden soll......Durch M. Paulum Jenisch, Annaebergensem......Gedruckt zu Leipzig, Typ. Beerwaldin.... .Im MDCVI. Jahr. 4to. 55 pp.

"Wetter," in old German, signifies thunderstorm, not weather, as at present.

**Joannes Cantuariensis.**

Jo. Archiepiscopi Cantuariensis Perspectiua communis. Fol. 20 ff. [In fine:] Impressum hoc opus Venetiis per Io. Baptistam Sessam. Cal. Iunii MCCCCCIIII. Diligentissime emendata. Per L. Gauricum Neapolitanum ......With many figures in the text.

Scarce. Deals also with the rainbow. The original edition was issued at Milan about 1480. *Brunet* (III 534). *Graesse* (III 463). I possess also an Italian translation by *G. P. Gallucci.* (I tre libri della perspettiva commvne ...... In Venetia, appresso gli Heredi di Giouanni Varisco. MDXCIII. 8vo. (8), 48 ff.) The author is John Peckham, Archbishop of Canterbury; see also the article *Hartmann.*

**[Kalender.]**

[I possess some old German almanacs or "Kalender" which contain the probable weather for the year for which they have been issued. It would occupy too much space to publish the whole title; it may be sufficient to give the year and the place :]

Neu und alter römischer Allmanach ......1592. Durch Barthol. Scultetum. Görlitz. 4to.

Newer vnd alter Schreib-Calender ......1641......Danzig ......4to.

Alter und neuer Schreib-Calender ......1653......Braunschweig. 4to.

Alter und neuer Schreibkalender......1655......Nürnberg......4to.

M. Stephani Fuhrmann Zeitbuch......1657......Lüneburg......4to.

Vollständiger Jahr-Calender......1664......Frankfurt a.M.......4to.

Alter und neuer Zeit- und Wunder-Calender. 1679. Nürnberg. 4to.

Neuer und alter Schreib-Calender ......1691......Danzig......4to.

Hamburgischer Historien-Calender......1695......Hamburg......4to.

**Kepler**, Johann. **[Keppler.]**

Ioannis Kepleri S. C. Maiest. mathematici strena seu de niue sexangula ...... Francofvrti ad Moenvm, apud Godefridum Tampach. Anno MDCXI. 4to. 24 pp. With some woodcuts in the text.

Scarce. Earliest special tract dealing with the figure of snow crystals. *Graesse* (IV 11). *Hellmann* (234).

**Kircher**, Athanasius.

1. Athanasii Kircheri Fvldensis Bvchonii, e Soc. Iesv. Magnes siue de arte magnetica opvs tripartitvm quo praeterqvam qvod vniversa magnetis natura, eiusque in omnibus artibus & scientijs vsus noua methodo explicetur, e viribus quoque & prodigiosis effectibus magneticarum, aliaramque abditarum naturae motionum in elementis, lapidibus, plantis & animalibus elucescentium, multa hucusque incognita naturae arcana per physica, medica, chymica, & mathematica omnis generis experimenta recluduntur. Sumptibus Hermanni Scheus sub signo reginae. Romae, ex typographia Ludouici Grignani. MDCXLI ..... 4to. (16) ff. 916 pp. (8) ff. Frontispiece. With many plates and woodcuts in the text. Original edition.
2. [The same work]. Editio secunda post Romanam multo correctior. Coloniae Agrippinae. Apud Iodocum Kalcoven. Anno MDCXLIII......4to. (15) ff., 797 pp., (19) ff., frontispiece, many plates and woodcuts in the text.

**Kircher**, Athanasius—Continued.

3. [The same work]. Editio tertia. Ab ipso authore recognita, emendataque, ac multis nouorum experimentorum problematis aucta. Romae MDCLIV. Sumptibus Blasii Deuersin, & Zanobii Masotti Bibliopolarum. Typis Vitalis Mascardi......Folio (16) ff. 618 pp. (14) ff. Frontispiece and many woodcuts in the text.

4. Athanasii Kircheri e soc. Jesu mundus subterraneus, in xii libros digestus; quo divinum subterrestris mundi opificium......exponuntur......Editio tertia ......Tomus I. Amstelodami. Apud Joannem Janssonium à Waesberge & filios. Anno CIƆIƆCLXXVIII. Large fol. (10) ff., 366 pp., (3) ff. Frontispiece and portrait of the author. Tomus II. Amstelodami. Ex officina Janssonio-Waesbergiana. Anno 1678. Large fol. (5) ff., 507, (9) pp.

Both volumes replete with woodcuts in the text (some of which are movable), and large folding plates. Best edition; first issued in 1665.

"De aeris & ventorum causis, natura, viribus & varietate" pp. 210 to 246. Contains the earliest map of ocean currents. *Brunet* (III 666). *Graesse* (IV 21). *Hellmann* (237).

**Kornmann**, Heinrich.

Templvm natvrae historicvm Henrici Kornmanni ex Kirchaina Chattorum; in qvo de natvra et miracvlis qvatvor elementorum: ignis, aeris, aqvae, terrae ......disseritur......Darmbstadii, curante Ioh. Iac. Porssio. A. 1611. Small 8vo. 334 pp. *Graesse* (IV 45).

**Lana**, Francesco [de Lanis].

Prodromo ouero saggio di alcune inuentioni nuoue premesso all' arte maestra, opera che prepara il P. Francesco Lana Bresciano della compagnia di Giesv. Per mostrare li piu reconditi principij della naturale filosofia...... In Brescia, MDCLXX. Per li Rizzardi......Fol. (4) ff. 252 pp. 20 plates.

Deals with meteorological instruments. Famous for the description of "una nave, che camini sostentata sopra l'aria, a remi, & a vele, quale si dimostra poter riuscite in prattica." (Cap. 6). *Brunet* (III 822). *Gamba* (1953). *Graesse* (IV 100). *Ricarrdi* (II 12).

**Latini**, Brunetto.

Il tesoro di M. Brvnetto Latino Firentino, precettore del diuino poeta Dante nel qual si tratta di tutte le cose che a mortali se apertengono. MDXXVIII. Small 8vo. (8) ff. 271 pp. (1) f. [In fine:] Stampato in Vineggia per Gioan Antonio & fratelli da Sabbio......

Scarce edition of this famous Italian cosmography compiled in the thirteenth century. The second book deals with meteors. *Brunet* (I 1233). *Gamba* (587). *Graesse* (I 553). *Riccardi* (II 18).

**Le Grand**, Antoine.

Antonii le Grand historia naturae, variis experimentis et ratiociniis elucidata. Secundum principia stabilita in institutione philosophiae edita ab eodem authore. Editio secunda priori auctior. Londini. Apud J. Martin...... 1680. 4to. (6) ff. 431 pp. (8) ff. With frontispiece, portrait of the author, and woodcuts in the text. *Graesse* (IV 150). Original edition issued in 1673.

**Lemnius**, Levinus.

De miracvlis occvltis natvrae libri iiii......Avctore Levino Lemnio medico Zirizaeo. Antverpiae. Apud Christophorum Plantinum......MDLXXIIII. 8vo. (8) ff. 582 pp. (17) ff.

Contains much meteorological and magnetical matter. *Brunet* (III 972). *Graesse* (IV 159).

**Leotaud**, Vincent.

R. P. Vincentii Leotavdi Delphinatis Societ. Iesv, magnetologia; in qva exponitvr nova de magneticis philosophia. Lvgdvni, Sumptibus Lavrentii Anisson. MDCLXVIII......4to. (6) ff. 420 pp. (3) ff. With woodcuts.

Scarce. *Graesse* (IV 168).

**Leupoldus [Leopoldus]**, Dux Austriae.

Compilatio Leupoldi ducatus austrie filij de astrorum scientia decem continentis tractatus. 4to. (94) ff. [In fine:] Uenetijs per Melchiorem Sessam: r Petrum de Rauanis socios. Anno incarnationis domini MCCCCCXX. die. xv. Julij. With many woodcuts.

Scarce. Tractatus sextus de mutatione aeris (ff. 42 to 46). The original edition issued at Augsburg in 1489. *Brunet* (III 1033). *Graesse* (IV 168).

**[Leurechon**, Jean].

1. Recreation mathematiqve composee de plvsievrs problemes plaisants et facetievx en faict d'arithmeticque, geometrique, mechanique, optique, catoptrique, & autres parties de cette belle science. Augmentee de plusieurs notes......A Paris, chez Iean Moreav......MDCXXVI...... 12mo. 347 pp. With many woodcuts. On p. 191: "Probleme lxxvi. Du Thermometre, ou Instrument pour mesurer les degrez de chaleur ou de froidure, qui sont en l'air," with a woodcut representing two thermometers. The original edition was issued in 1624, signed Van Etten, pseudonym of Leurechon. *Brunet* (IV 1140 "Recreation"). *Graesse* VI *b*, 46).

2. Examen dv livre des recreations mathematiqves et de ses problemes en geometrie, mechanique, optique, & catoptrique......par Clavde Mydorge ......A Paris, chez Rolet Bovtonne....4.MDCXXXVIII. 8vo. (8) ff. 280. 106 pp. (6) ff. 39 pp. With many woodcuts.

   The same problem on pp. 149–151.

3. Thavmatvrgvs mathematicvs, id est, admirabilivm effectorvm e mathematicarvm disciplinarvm fontibvs proflventium sylloge. Casparo Ens L. collectore & interprete......Coloniae. Apud Constantinvm Münich. Anno 1636. Small 8vo. (6) ff. 291 (12) pp. Woodcuts.

   Latin translation by Casper Ens, who modified the title of the above-named problem into: "De thermometra, siue instrumento Drebiliano, quo gradus caloris, frigorisque aëra occupantis explorantur. (pp. 126–128)." Thus, Ens seems to be the first who ascribed the invention of the thermometer to Drebbel.

4. [The same.] Nunc denuo correctior & auctior......Coloniae......Anno 1651. Small 8vo. (4) ff. 303., (14) pp. Woodcuts.

   Annexed to this edition is, at least in my copy: Thavmatvrgi physici prodromvs id est problematvm physicorum liber singularis, lectu iucundus & vtilis. Ad Cl. V. Aegidivm Gelenivm. A. D. J. M. Coloniae. Apud Constantinvm Münich. Anno MDCXLIX......Small 8vo. 201. (7) pp. Contains many meteorological problems.

5. Mathematische Vermaecklyckheden, verdeylt in III Deelen......Ghetranslateert uyt het Fransch in Nederduytsche tale......door Wynant van Westen......Den tweeden druck op nieus oversien ende verbetert. Tot Arnhem. By Jacob van Biesen......1641. Small 8vo. (8) ff. 257. (13) pp. (1) f. [blank], 61, (5), pp., (1) f. 41 pp. Woodcuts.

   Dutch translation, the earliest being issued in 1636. It is a curious fact that in the Dutch edition the name of Drebbel, a Dutchman, as inventor of the thermometer, is not mentioned (p. 142: "Van een Instrument, om te kennen de graden ofte deelen van de koude ende hitte des Luchts, ghenaemt Thermometre").

**Lilly**, William.

An astrologicall discourse of the three svns seen the 3 of April, 1647. Small 4to. (5) ff. One woodcut. Scarce. *Lowndes* (Pt. v 1362).

**Linus**, Franciscus [**Line**, Francis.]

Tractatus de corporum inseparabilitate in quo experimenta de vacuo, tam Torricelliana, quam Magdeburgica, & Boyliana, examinantur verâque eorum causâ detectâ, ostenditur, vacuum naturaliter dari non posse; Unde & Aristotelica de rarefactione sententia, tam contra assertores vacuitatum, quam corpusculorum, demonstratur......Autore Francisco Lino. Londini. Typis Thomae Roycroft......CIƆIƆCLXI. Small 8vo. (8) ff. 189, (3) pp. 4 folding copper-plates.

**Lonicerus**, Joannes [**Lonitzer**, Johann].

De meteoris, compendivm, ex Aristotele, Plinio, & Pontano, Perinde ac Ioannes Lonicervs congerebat libri IIII......Franc. Apud. Chr. Egenolphum. Small 8vo. 40 ff. [In fine:] MDXLVIII.

Scarce second edition (first published at Wittenberg in 1532) of a little work, used as a text-book of meteorology in the university of Marburg. *Hellmann* (299).

**Lucretius Carus**, Titus.

T. Lvcretii Cari de rervm natvra libri sex, mendis innumerabilibus liberati...... ab Oberto Gifanio Bvrano......Antverpiae, Ex officina Christophori Plantini. CIƆCILXV. Small 8vo. (24) ff. 477 pp. [In fine:] MDLXVI.

Contains also the physics and meteorology of Epicurus (pp. 235–272). *Brunet* (III 1217). *Graesse* (IV 287).

**Magnus**, Olaus.

Olaj Magni Historien der mitternächtigen Länder, von allerlei Thun, Wesens, Condition, Sitten, Gebreuchen, Aberglauben, ......Ausz selb eigner erfahrnusz viler Jar lang, zu Wasser vnd Landt zusamen verzeichnet vnd beschryben durch weilandt den hochwürdigsten Herrn, Herrn Olavm Magnvm ausz Gothien......Hernach aber ins Hochteutsch gebracht, vnd mit fleisz transferiert durch Johann Baptisten Ficklern, von Weyl, vor dem Schwartzwald ...... Getruckt zu Basel, etc. ...... Fol. (30) ff. (last blank), DCXXIII pp. [In fine:] Getruckt zu Basel in der Officin Henricpetrina, im Jar MDLXVII. Large fold. map of Scandinavia and many woodcuts in the text.

The original edition in Latin was published at Rome in 1555. It contains many meteorological chapters, *i. a.*, the earliest figures of snow-crystals and of frost-figures on the windows. *Brunet* (III 1302). *Graesse* (IV 339).

**Maiolo**, Simeone.

Dies canicvlares hoc est colloqvia tria et viginti physica, nova et penitvs admiranda ac summa iucunditate concinnata per Simonem Maiolvm episcopum Vulturariens.......Editio altera priori auctior & correctior. Mogvntiae. Ex officina Ioannis Albini......MDCVII. 4to. (4) ff., 780 pp., (46) ff.

Original edition issued in 1597. Encyclopaedic work of great reputation in the 17th century. "Meteora" pp. 1–54. *Brunet* (III 1323). *Graesse* (IV 345). *Riccardi* (II 73).

**Manutio**, *Paolo.*

De gli elementi, e di molti loro notabili effetti. In Venetia, MDLVII......small 4to. xxxiiii ff. [Aldus].

Dedicated by Paolo Manutio to Paolo Giustiniano. *Brunet* (III 1383). *Graesse* (IV 375).

**Medina**, Pedro de.

1. L'arte del navegar, in laqval si contengono le regole, dechiarationi, secreti, & auisi, alla bona navegation necessarij. Composta per l'eccel. Dottor M. Pietro da Medina, & tradotta de lingua spagnola in volgar Italiano, à beneficio, & vtilità de ciascadun nauigante. In Vinetia, ad instantia di Gioanbattista Pedrezano......MDLV. 8vo. (12), cxxxvii ff. [In fine:] MDLIIII. With many woodcuts in the text.

   Rare first Italian translation of one of the earliest works on navigation, the Spanish original of which (1545) is excessively scarce. "Libro terzo de li venti, et de le lor qvalita, et di soi nomi, et come si ha da navigar per essi" (f. xxvi to li). "Libro sesto della aguggia, over bossolo da navigar." (f. cviii to cxvi). The author still denies the variation of the magnetic needle, discovered by Christopher Columbus in 1492.

2. Arte del navigare dell'eccel. Dottor Pietro da Medina. Nella quale copiosamente si tratta tutto quello, che appartiene alla nauigatione, e sua cognitione......Di nouo ampliata, & corretta...... In Venetia, MDCIX. Appresso Tomaso Baglioni. 8vo. (8), 137 ff. With many woodcuts in the text. *Brunet* (III 1572). *Graesse* (IV 462). *Picatoste* (185).

**Megenberg**, Konrad von.

[Buch der Natur]. Small fol. (171) ff. with engravings. [In fine:] Hie endet sich das buch der Natur das hat getruckt Hanns Schönsperger in d'keiserlichen stat Augspurg. Als man zalte nach der geburt Cristi MCCCCXCIX iar.

German chapbook of natural sciences, the meteorological part of which I have dealt with in my paper on "Meteorologische Volksbücher." *Brunet* (I 1366). *Graesse* (I 562). *Hain* (4046).

**Melanchthon**, Philipp.

Initia doctrinae physicae, dictata in academia Witebergensi a Philip Melanth. Iterum edita cum indice & annotationibus......Vitebergae excudebat Iohannes Crato. Anno MDLXVII. Small 8vo. (6) ff. 393, (10) pp. Original edition isued in 1555. *Graesse* (IV 468).

[**Memoirs.**]

Memoires de mathematique et de physique, tirez des registres de l'Académie Royale des Sciences. A Paris, de l'imprimerie royale. MDCXCII. 4to. (2) ff. 195 (5) pp. With many plates.

Contains *i. a.* the results of the earliest observations of rainfall made at the Paris Observatory by Sedileau (p. 25-32).

**Meseallach.** (**Messahalah.**)

Meseallach r Ptholemeus de electionibus. MDVIIII. Felicibus astris prodeat in orbem ductu Petri Liechtenstein. Small 4to. (10) ff.

Contains some passages of astro-meteorology. *Graesse* (IV 503).

**Mizaldus**, Antonius [**Mizauld**, Antoine.]

1. Ephemerides aeris perpetvae: sev popularis & rustica tempestatum astrologia, vbique terrarum & vera, & certa. Prolegomena in easdem. Vbi de aëria brutorū praesagitione, & facili methodo praedicendarum omnium aurae commotionum ex solis phaenomenis. Avtore Antonio Mizaldo Monlvciano. Lvtetiae. Apud Iacobum Keruer ......1554.......Small 8vo. 175 ff.

   Scarce original edition. Fine copy with colored initials.

2. Ephemerides aeris perpetvae: sev popvlaris & rustica tempestatum astrologia, vbique terrarum & vera, & certa. Avtore Antonio Mizaldo Monlvciano. Antverpiae. Apud Ioannem Bellerum......1560. Small 8vo. 234 pp. *Brunet* (III 1778). *Graesse* (IV 553).

**Monoconys,** Balthasar de.

1. Jovrnal des voyages de Monsievr de Monconys, conseiller du roy en ses conseils d'estat & priué, & lieutenant criminel au siege presidial de Lyon. Où les sçauants trouueront vn nombre infini de noueautez, en machines de mathematique, experiences physiques, raisonnemens de la belle philosophie, curiositez de chymie, & conuersations des illustres de ce siecle; outre la description de diuers animaux & plantes rares......Enrichi de quantité de figures en taille-douce des lieux & des choses principales......Publié par le Sieur de Liergves son fils. Premiere partie. Voyage de Portugal, Provence, Italie, Egypte, Syrie, Constantinople, & Natolie. A Lyon, Chez Horace Boissat & George Remevs. MDCLXV.......4to. (4) ff. 491 pp. Seconde partie. Voyage d'Angleterre, Païs-Bas, Allemagne, & Italie. Ibidem. MDCLXVI.......(2) ff. 503 pp. Troisieme partie. Voyage d'Espagne, Mort de Sultan Hibrahim, Lettres sçauantes, algebre, vers, & secrets. Ibidem. MDCLXVI.......(4) ff. 60, 56, 44, 96 pp. (16) ff. (last blank). With many plates.

   Scare original edition of this esteemed work, especially important for the history of all mathematical and physical sciences in the beginning of the seventeenth century.

2. Des Herrn de Monconys ungemeine und sehr curieuse Beschreibung seiner in Asien und das gelobte Land, nach Portugall, Spanien, Italien, in Engelland, die Niederlande und Teutschland gethanen Reisen, worinne er allerhand artige und nicht gemeine, so chymische als medicinische, mechanische und physicalische Experimenta,seine besondere Conversation mit berühmten und gelehrten Leuten......angeführet, zum Theil auch die Städte, Gebäude, Paläste, Kirchen......abgezeichnet hat; alles mit schönen Kupffern versehen, und anjetzo zum erstenmahl aus der frantzösischen in die hochteutsche Sprache übersetzet von M. Christian Juncker......Leipzig und Augspurg. Auff Unkosten Lorentz Kroniger und Gottlieb Göbels sel. Erben......1697. 4to. Frontispiece. (1) f. 1024 pp. (8) ff. This translation is abbreviated. *Graesse* (IV 574).

**Montanari,** Geminiano.

1. La fiamma volante gran meteora veduta sopra l'Italia la sera del 31. marzo MDCLXXVI. Specvlazioni fisiche, et astronomiche espresse dal Dott. Geminiano Montanari......In Bologna, per li Manolessi, MDCLXXVI. 4to. 95 pp. 1 plate.

   Dedication copy of the author to Guiseppe del Papa. Relates to the calculation of heights by means of the barometer. *Graesse* (IV 583). *Riccardi* (II 172).

2. L'Astrologia convinta di falso col mezzo di nuoue esperienze, e ragioni fisico-astronomiche, ò sia la caccia del frvgnvolo di Geminiano Montanari Modanese......In Venetia, MDCLXXXV. Per Francesco Nicolini......4to. xiv, 158 pp.

3. Le forze d'Eolo. Dialogo fisico-matematico sopra gli effetti del vortice, ò sia turbine, detto negli Stati Veneti la bisciabuova che il giorno 29 Luglio 1686 ha scorso, e flagellato molte ville, e luoghi de' territorj di Mantova, Padova, Verona, &c. Opera postvma del Sig. Dottore Geminiano Montanari Modanese, Astronomo, e Meteorista dello studio di Padova. In Parma, ad instanza d'Andrea Poletti. 1694. 12mo. (24) ff. 342 pp. (3) ff. 1 plate.

   Contains also a "Discorso del vacuo" (pp. 271 to 312).

**Morin,** Jean Baptiste.

Astrologia gallica principiis & rationibus propriis stabilita, atque in XXVI. libros distributa. Non solum astrologiae judiciariae studiosis, sed etiam

**Morin,** Jean Baptiste—Continued.

philosophis, medicis & theologis omnibus per-necessaria: quippe multa complectens eximia ad scientiss illas spectantia. Opera & studio Joannis Baptistae Morini, apud Gallos è Bellejocensibus Francopolitani, doctoris medici & Parisiis regii mathematum professoris. Ejus anagramma. Mira sapiens uni bono stat. Hagae-Comitis, ex typographia Adriani Vlacq. MDCLXI. Fol. (5) ff. xxi, xxxvi, 784 pp. Portrait of the author before the title, woodcuts.

Contains many astro-meteorological chapters.. *Graesse* (IV 608).

**Morisot,** Claude.

Orbis maritimi sive rervm in mari et litoribvs gestarum generalis historia: in qva inuentiones nauium......causae & genera ventorum, vsus pixidis nauticae, histiodromice, marium diuersi motus, aestusque, atque exundationes...... Authore Clavdio Bartholomaeo Morisoto Diuionensi. Divione, apud Petrvm Palliot......MDCXLIII......Large fol. (11) ff. 725 pp. (9) ff. With many large illustrations, fold. plates, and frontispiece.

**Muenster,** Sebastian.

Practick durch Sebastianū Műnster vsz den himelischen bewegungen vnd inflűssen gezogen, vnd vff das jar Christi MDXXXIII gestelt. Mars vnder den planeten ein herr dis iar. Getruckt zu Basel by Heinrichen Petri. 4to. (8) ff.

Contains weather prognostics for all months of the year 1533.

**Nagel,** Paul.

M. Pauli Nagelii deutzsche astrologische Practica, oder Prognosticum, auff das Jahr MDCXXII.......Gedruckt zu Leipzig durch Andream Oszwald. 4to. (20) ff. *Hellmann* (355).

**Najera,** Antonio de.

Sūma astrologica, y arte para enseñar hazer pronosticos de los tiempos, y por ellos conocer la fertilidad o esterilidad del año, y las alteraciones del aire, por el juyzio de los eclypses del sol, y luna, por la reuolucion del año, y mas en particular por las conjunciones, opposiciones, y quartos que haze la luna con el sol todos los meses y semanas. Dispuesta por el mejor, y mas racional estilo...... y el modo como se hazen todas estas impreciones metheorologicas en el aire, y tierra con otras muchas curiosidades aproposito. Compvesta por Antonio de Naiera mathematico Lusitano natural de la ciudad de Lisboa. A. S. Antonio de Padva. Año de 1632. En Lisboa. Por Antonio Aluarez......4to. (4) ff. 245, (5) pp.

Very scarce Spanish tract on astro-meteorology. *Picatoste* (209).

**Niphus,** Augustinus. [**Nifo,** Agostino.]

1. De liberatione a metu futuri diluuii. Augustini Niphi de Medicis Philosophi Suessani contra nonnullos iuniores ad Ludouicum Ferdinandum de Corduba Suessanorum Principem. Small 4to. (20) ff. [In fine:] Venetiis. iii. nonis Octobris MDXXIII. Andrea Gritti Duce Regnante.

   Relating to the inundation and deluge prophesied for the year 1524 by *J. Stöffler.*

2. Magni Avgvstini Niphi Medicis Philosophi Suessani, de verissimis temporum signis commentariolus. Ad illustrissimam Mariam Aragoniam, vasti marchionissam. Venetijs apud Hieronymum Scotum. 1540. Small 8vo. 143 p. *Graesse* (IV 678). *Riccardi* (II 199).

**Olympiodorus.**

1. *Ὀλυμπιοδώρου φιλοσόφου Ἀλεξανδρέως εἰς τὰ μετεωρα τοῦ Ἀριστοτέλους ὑπομνήματα. Ἰωάννου Γραμματικοῦ τοῦ Φιλοπόνου σχόλια εἰς τὸ ά τῶν μετεώρων τοῦ Ἀριστοτέλους.*

**Olympiodorus**—Continued.

Olympiodori philosophi Alexandrini in meteora Aristotelis commentarii. Ioannis Grammatici Philoponi scholia in primvm meteorvm Aristotelis...... Venetiis MDLI. Fol. 108 ff. [In fine:] Venetiis apud Aldi filios, expensis nobilis uiri Federici de Turrisanis eorum auunculi. MDLI.

Title in Greek and Latin, but text only in Greek.

2. Olympiodori philosophi Alexandrini in meteora Aristotelis commentarii. Ioannis Grammatici Philoponi scholia in I. meteorvm Aristotelis. Ioanne Baptista Camotio philosopho interprete, ad Philippvm Ghisilerivm, eqvitem Bononien. splendidissimvm et senatorem clariss......Venetiis, MDLI. Fol. (4) 139. (1) ff. [In fine:] Venetiis, apvd Aldi filios. Expensis uero nobilis viri Domini Federici de Turisanis eorum auunculi. MDLI. *Brunet* (IV 186). *Graesse* (V 22).

**Oudenhoven**, Jacob van.

Antiquitates cimbricae renovatae, Dat is, vernieude oudtheden der Cimbren. Of een raer verhael van de Cimbren end Cimbersche Vloet. Ende van't hoogh water 1681. en hoogen vloet van den 26. January 1682. Door Jacob van Oudenhoven. Gedructk tot Haerlem, By Simon Swart......1682. Small 12mo. (12) ff, 212, (3) pp. *Bierens de Haan.*

**Papa**, Giuseppe del

1. Lettera intorno alla natvra del caldo, e del freddo, scritta all' illvstrissimo Sig. Francesco Redi, Gentilvomo Aretino, dal Dottore Givseppe Del Papa da Empoli. Lettore di Logica nell'vniversità di Pisa. In Firenze. Per Francesco Liui. 1674......Small 8vo. 250 pp. (1) f.

   Original edition mentioned by *Gamba* (2042), who erroneously calls the size quarto instead of octavo.

2. Della natvra dell'vmido, e del secco, lettera all'illvstrissimo Sig. Francesco Redi scritta da Givseppe Del Papa da Empoli Professore straordinario di medicina pratica nella vniuersità di Pisa. In Firenze, per Vincenzo Vangelisti. MDCLXXXI......4to. 220 pp. 2 copper-plates.

   Dedication copy of the author to the famous Vincenzio Viviani, who made the first Torricellian experiment of the barometer. *Gamba* (2044).

**Paracelsus**, Aureolus Pil. **Theophrastus.** [Bombast von **Hohenheim.**]

1. Das dritte Buch. Von oberen Wunderwercken vnd Witterungen. Dariñ mit grūd der warheit dargethan wirt dass alle Witterungen, wie sich die jmmer zeigen mögen, nicht ausz vergeblichem zufall, sondern ausz wolbewuszter fürsehung Gottes, ausz den H. himlischē Schatzkästen Gottes, mit gnaden mit vngnaden, wie wirs verdienen, herab zu vns kommen. Getruckt Anno 1585. Small 4to. (3) ff. 69 pp.

   Seems to be the third part of the "Cyclopaedia Paracelsica Christiana," see Theophrastus Paracelsus. Eine kritische Studie von Friedrich Mook. Würzburg, 1876. 4to. (p. 83).

2. Avr. Phil. The. Paracelsi philosophorvm atqve medicorvm hactenvs omnium facile principis, de meteoris liber vnus. De matrice liber alius. De tribus principijs liber tertius. Quibus astronomica & astrologica fragmenta quedam accesserunt. Omnia ex versione Gerardi Dorn ..... Basileae per Petrvm Pernam. 8vo. (7) ff. 223 pp.

   Scarce. See the above-named work of Mook Nr. 243. *Graesse* (V 127).

**Pascal**, Blaise.

1. Traitez de l'eqvilibre des liqvevrs, et de la pesantevr de la masse de l'air. Contenant l'explication des causes de divers effets de la nature qui n'avoient point esté bien connus jusques ici, & particulieremēt de ceux que l'on avoit attribuez à l'horreur de vuide. Par Monsieur Pascal. A Paris, Chez Gvil-

**Pascal**, Blaise—Continued.

laume Desprez......MDCLXIII......12mo. (14) ff. 232 pp. (4) ff. 2 folded copper plates.

Original and scarce edition of this famous treatise of Pascal published by his brother-in-law, Périer, who made "la grande expérience" (viz., of the barometer) on the Puy-de-Dôme. For more details see the introduction to my meteorological reprints, "Neudrucke," No. 2.

2. [The same work.] Seconde edition. A Paris, en la boutique de Charles Savreux......MDCLXIV. 12mo. (13) ff. 232 pp. (3) ff. 2 folded copper plates.

3. [The same work.] A Paris, Chez Guillaume Desprez......MDCXCVIII...... 12mo. (12) ff. 238 pp. 2 folded copper plates.

Last separate edition of the "Traitez" incorporated later in the collected works of the author. *Brunet* (IV 400). *Graesse* (V 147).

**Pasch**, Georg.

Georgii Paschii Gedanensis......de novis inventis quorum accuratiori cultui facem praetulit antiquitas tractatus......Editio secunda priori quarta parte auctior......Lipsiae, sumptibus haeredum Joh. Grossi. MDCC. 4to. (10) ff. 812 pp. (63) ff. Chapter vii: "De inventis physico-mathematico-mechanicis" (pp. 510–811). *Hellmann* (372).

**Paulus**, Venetus.

[Expositio lib. natural. Aristotelis]. Fol. (222) ff. [In fine:] Explicit sexta & vltima pars sūme naturaliū acta & compilata per reuerendū artium & theologie doctorem magistrum Paulū de Uenetijs ordinis fratrū heremitarū sancti Augustini transumpta ex ꝓprio originali manu p'pia pfati magistri efecto Venetijs impressionē habuit īpensis Johānis de Colonia sociiq; eius Johannis māthen de Gherretzem. Anno a natali christiano. MCCCCLXXVI. With illuminated initials.

Scarce. "Liber Methaurorū" occupies 20 ff. *Brunet* (IV 453). *Graesse* (V 175). *Hain* (12515).

**Perrault**, Pierre.

De l'origine des fontaines. A Paris, Chez Pierre le Petit......MDCLXXIV. Small 8vo. (10) ff. 353 (7) pp. Copper plate before the title.

Anonymous work, containing *inter alia* on p. 200 the results of the earliest series of systematic and regular observations of rainfall, taken by the author at Paris from October, 1668, to January, 1674. There is another (title) edition issued at Paris, chez Jean de la Caille, in 1678. P. Perrault's work was incorporated in "Oeuvres diverses de physique et de mecanique de Mrs C. & P. Perrault......divisées en deux volumes. A Leide, chez Pierre Van Der Aa. MDCCXXI. 4to. (pp. 715–850.) Pierre Perrault is here erroneously referred to "de l'Académie Francoise;" only his brother Claude belonged to it.

**Petavius**, Dionysius.

Vranologion sive systema variorvm avthorvm, qvi de sphaera, ac sideribvs, eorvmque motibvs graece commentati sunt. Sunt autem horum libri. Gemimi, Achillis Tatij, Isagoge ad Arati Phaenomena. Hipparchi libri tres ad Aratum. Ptolemaei de apparentiis. Theodorae Gazae de mensibus. Maximi, Isaaci Argyri duplex. S. Andreae Cretensis Computi. Omnia vel graece ac latine nunc primum edita, vel ante non edita. Cura & studio Dionysii Petavii Aurelianensis e Societate Iesv. Quod esse potest luculentissimum auctarium operis de doctrina temporum. Accesserunt variarum dissertationum libri octo, ad authores illos intelligendos imprimis vtiles, eodem authore. Lvtetiae Parisiorvm, sumptibus Sebastiani Cramoisy......MDCXXX......Folio. (8) ff. 424 pp. (8) ff. 338 pp. (5) ff.

**Petavius**, Dionysius—Continued.

Very important work for the study of the old authors, Aratus, Geminus, Ptolemaeus, and others, who have written on astro-meteorological subjects; contains also a "Calendarium vetus Romanum cum ortu occasuque stellarum ex Ovidio, Columella, Plinio a Dionysio Petavio confectum," giving a fair idea of what we would call at present the mean annual range of the meteorological phenomena, at the time of the Romans. *Brunet* (IV 527). *Graesse* (V 218).

**Petit**, Pierre.

Observation tovchant le vvide, faite povr la premiere fois en France: contenuë en vne lettre écrite à Monsieur Chanut Resident pour sa Majesté en Suede. Par Monsieur Petit Intendāt des fortifications, le 10 nouēbre 1646. Auec le discours qui en esté imprimé Pologne sur le mesme sujet, en juillet 1647. A Paris, Chez Sebastien Cramoisy......MDCXLVII......Small 8vo. (6) ff. 68 pp.

Very scarce. M. Petit made at Rouen the first experiments with the barometer in France, and demonstrated them to his friend Blaise Pascal; see the introduction to No. 2 of my meteorological reprints. The "discours" announced in the title begins on p. 25 with the following separate title:

Demonstratio ocvlaris. Loci sine locato: Corporis successiue moti in vacuo: Luminis nulli corpori inhaerentis. A Valeriano Magno Fratre Capvccino, exhibita. Sereniss. Principibvs Vladislao iv. Regi, & Lvdovicae Mariae Reginae Poloniae & Sveciae, Magnis Ducibus Lithuaniae, &c., Virgini Deiparae ex voto sacra & dicata. Varsaviae. In officina Petri Elert S. R. M. Typographi.

Valeriano Magni (or Magno) pretended in this pamphlet, the original edition of which seems to be extremely scarce, to have invented the barometer independently of and previous to Torricelli. For another reprint, see title under "Elephantutius." Professor Jacoli mentions five different editions of this little book in Boncompagni's Bulletino di Bibliografia e di Storia delle Scienze matematiche e fisiche. Vol. viii. p. 288.

**Peucer**, Caspar.

Commentarivs de praecipvis divinationvm generibvs, in qvo a prophetiis, avthoritate diuina traditis......recognitus vltimo, & auctus, ab avthore ipso Casparo Pevcero D......Francofvrti, apud Andreae Wecheli heredes...... MDXCIII. 8vo. (16) ff., 1 fold. table, 738 pp. (26) ff.

"De Meteorologia" on pp. 556–600. Original edition published in 1553. *Brunet* (IV 582). *Graesse* (V 245).

**Piso**, Guilelmus.

Guilelmi Pisonis medici Amstelaedamensis de Indiae utriusque re naturali et medica libri quatuordecim, quorum contenta pagina sequens exhibit. Amstelaedami, Apud Ludovicum et Danielem Elzevirios. A° CIƆIƆCLVIII. Fol. (12) ff., 327, (5), 40, 226, (2) pp.

Contains "Georgii Marcgravii de Liebstad tractatus topographicus & meteorologicus Brasiliae......," with the meteorological diaries for the years 1640 to 1642 in extenso, these being perhaps the earliest meteorological observations made in South America. *Brunet* (IV 677). *Graesse* (V 305). *Hellmann* (321 "Marggraf").

**Plot**, Robert.

De origine fontium, tentamen philosophicum. In praelectione habita coram Societate Philosophica nuper Oxonii instituta ad scientiam naturalem promovendam. Per Rob. Plot. L.L.D. Custodiae Mvsaei Ashmoleani Oxoniae Praepositum. Et Regiae Societatis Londini Secretarium. Oxonii e theatro Sheldoniano An. Dom. MDCLXXXV .....Small 8vo. (10) ff. 187 pp., and frontispiece.

**Plot,** Robert—Continued.

Relating to rainfall. The author mentions on p. 59 Chr. Wren's self-registering rain gauge, the earliest instrument of this kind. *Lowndes* (Pt. III, 1886).

**Pontanus,** Joannes Jovianus. [**Pontano,** Giovanni Goviano.]

1. Pontani opera. Vrania, siue de stellis libri quinq; Meteororum liber unus. De hortis hesperidum libri duo. Lepidina siue postorales (sic!) pompae septem. Item Meliseus. Maeon. Acon. Hendecasyllaborum libri duo. Tumulorum liber unus. Neniae duodecim. Epigrammata duodecim. Quae uero in toto opere habeantur in indice, qui in calce est, licet uidere. [In fine:] Venetiis in aedibus Aldi Ro. mense augusto MDV. Small 8vo. (243) ff. Two parts (the first ending on fol. 184a) in one volume.

   Original and scarce edition of Pontano's poetical treatise on meteorology, which was much appreciated in the 16th century. *Riccardi* (II 301).

2. Qvae in hoc enchyridio contineantvr. Ioannis Iouiani Pontani Vrania seu de stellis libri quinq; Meteororum liber unus......[In fine:] Florentiae ex officina Philippi de Giunta Florentini sumptibus suis Anno MDXIIII. Men. Iunio......Small 8vo. 184, (4) ff. The second volume contains 187, (9) ff. *Riccardi* (II 302).

3. Pontani opera. Vrania, siue de stellis libri quinq; Meteororum liber unus ......[In fine :] Venetijs in aedibus haeredum Aldi Manutij, & Andreae soceri, mense Augusto, MDXXXIII. Small 8vo. (8) 247, (1) ff.

4. De meteoris Iohannis Ioviani Pontani ad Lvcivm Franciscvm filivm, liber seorsim expressvs. CIↃIↃXXCII. Small 8vo. (32) ff.

   Scarce. Without place and name of printer, but probably printed at Wittenberg by J. Lufft, for the type and the ornament on the title page are quite the same as those used in the edition of Frytsch's De Meteoris issued in 1583 by the same printer. *Brunet* (IV 806). *Graesse* (V 406).

**Porta,** Johannes Baptista. [**Porta,** Giambattista.]

1. Io. Bapt. Portae Neapolitani magiae natvralis libri xx. Ab ipso authore expurgati, & superaucti, in quibus scientiarum naturalium diuitiae, & delitiae demonstrantur ...... Neapoli, apud Horatium Saluianum. D. (sic!) D. LXXXVIIII. Fol. (8) ff. 303 pp. With many woodcuts in the text and a portrait of the author on the back of the title.

   Best edition of this famous work; chapter vii "De miraculis magnetis" is of special interest for the history of magnetism. The first edition, containing only 4 books, was published in 1558, the first augmented, with 20 books, in 1569. *Riccardi* (II 306) enumerates 23 different editions, besides the translations into Italian, French, German, and English.

2. Io. Baptistae Portae Lyncei Neapolitani de aeris transmutationibus libri iiii. In quo opere diligenter pertractatur de ijs, quae, vel ex aere, vel in aere oriuntur. Μετεωρολόγων multiplices opiniones, qua illustrantur, qua refelluntur. Demum variarum causae mutationum aperiuntur. Romae, apud Iacobum Mascardum MDCXIV......4to. (5) ff. 1 fold. table, 211 (5) pp. With woodcuts in the text. *Brunet* (IV 825). *Graesse* (V 417). *Riccardi* (II 306).

3. Io. Bap. Portae Neapolitani de distillatione lib. ix. quibus certa methodo, multipliciq; artificio, penitioribus naturae arcanis detectis, cuiuslibet mixti in propria elementa resolutio, perfecte docetur. Romae, MDCVIII. Ex typographia Reu. Camerae Apostolicae......4to. (8) ff. 154 pp. (3) ff. With

**Porta**, Johannes Baptista—Continued.

woodcuts in the text and a portrait of the author. Original edition issued at Naples in 1601.

I possess also the Italian translation: I tre libri de'spiritali di Giovambattista Della Porta Napolitano. Cioè d'inalzar acque per forza dell' aria. In Napoli, Appresso Gio. Iacomo Carlino, MDCVI. Small 4to. 98 pp. (1) f. Woodcuts. On p. 76 one of the earliest figures of the thermoscope.

**Proclus**, Diadochus.

1. Procli de sphaera liber I. Cleomedis de mvndo, siue circularis inspectionis meteororum libri ii, Arati Solensis phaenomena, siue apparentia. Dionysii Afri descriptio orbis habitabilis. Omnia graece & latine ita coniuncta, ut conferri ab utriusq; linguae studiosis possint......Vna cum Io. Honteri Coronensis de cosmographiae rudimentis duplici editione, ligata scilicet & soluta......Basileae per Henricum Petri. Small 8vo. (16) ff. 75 pp., and pp. 301–985. [In fine:] Anno Domini MDLXI. Many woodcuts and maps.

   Honter's cosmography contains a chapter: "De Ventis."

2. *Προκλου του Διαδοχου Παραφρασις εις την του Πτολεμαιου τεςράβιβλον.* Procli Diadochi paraphrasis in Ptolemaei libros iv de siderum effectionibus. A Leone Allatio e graeco in latinum conversa. Lvgdini Batavorvm, ex officini Francisci Moyardi......1654. Small 8vo. (4) ff. 294 pp. *Brunet* (IV 894). *Graesse* (V 453).

**Ptolemaeus**, Claudivs.

1. Clavdii Ptolemaei Pelusiensis Alexandrini omnia quae extant opera, praeter geographiam, quam non dissimili forma nuperrime aedidimus: summa cura & diligentia castigata ab Erasmo Osualdo Schrekkenfuchsio, & ab eodem isagoica in Almagestum praefatione, & fidelissimis in priores libros annotationibus illustrata, quemadmodum sequens pagina catalogo indicat. Basileae. Fol. (44) ff. 447 pp. [In fine:] Basileae in officina Henrichi Petri, Mense Martio, Anno MDLI. With many figures in the text.

   Contains the almagest, the quadripartitum (de judiciis), the significations, and the centiloquium.

2. Κλαυδιου Πτολεμαιου Πηλουσιεως τετραβιβλος συνταξις, πρὸς Σύρον ἀδελφόν. *Του αυτου καρπος, πρὸς τὸν αὐτὸν Σύρον.* Clavdii Ptolemaei Pelvsiensis libri quatuor, compositi Syro fratri. Eivsdem frvctvs librorum suorum, siue centum dicta, ad eundem Syrum......Basileae, Per Ioannem Oporinum. Small 8vo. (8) ff. 229 pp. [In fine :......MDLIII.]

3. Claudij Ptolemaei de praedictionibus astronomicis, cui titulum fecerunt Quadripartitū, grece & latine, libri iiii. Philippo Melanthone interprete. Eiusdem fructus librorum suorum, siue centum dicta, ex conuersione Iouiani Pontani......Basileae, Per Ioannem Oporinum. Small 8vo. 269 pp. [Without date, but 1553.]

4. Clavdii Ptolemaei, De praedictionibvs astronomicis, cui titulum fecerunt, Quadripartitum, libri iv. Eiusdem fructus librorum suorum, siue centum dicta. Editio posterior. Francofvrti, Typis Ioannis Bringeri... ..MDCXI. 12mo. (6) ff. [last f. blank], 308 pp. *Brunet* (IV 947). *Graesse* (V 496).

**Rabanus**, Maurus. [**Hrabanus.**]

[Opus de universo]. Epistola Rabani ad ludovicum regem inuictissimū &c. incipit foeliciter. f 167 *b*. col. 2. lin. 32 : potestas vna cooptio est.

Large fol. s. l. e. a. [1472 to 1475]. (167) ff.

Famous encyclopædic work like that of Isidorus Hispalensis. The 9th book contains the meteorology. *Brunet* (IV 1035). *Graesse* (VI[1] 2). *Hain* (13669).

**Raimondo**, Annibale.

Pronostico de Annibale Raimondo Veronese sopra li ecclyssi che farano il novembre prossimo che uiene, li effetti delli quali durerano per tutto il MDLVII......4to. (4) ff. [In fine :] Terminato in Venetia......1557. *Riccardi* (II 336).

**Ramazzini**, Bernardino.

Ephemerides barometricae Mutinenses anni MDCXCIV una cum disquisitione causae ascensus, ac descensus mercurii in Torricelliana fistula juxta diversum aeris statum Bernardini Ramazzini, M. P. ad illustrissimum, & celeberrimum virum D. Lucam Schröckium, Academiae Cæsareo-Leopoldinae Naturae Curiosorum Praesidem. His accessere epistolae excellentissimorum DD. D. Joan. Baptistae Boccabadati J. U. D. et D. Francisci Torti, M. P. Augustae Vindelicorum, impensis Kronigeri & haeredum Goebelii....1696. 4to. (2) ff. 60 pp. The authors "Opera amnia medica & physica"...... Genevae. Sumptibus Cramer & Perachon. MDCCXVI. 4to, contains also these tracts. *Riccardi* (II 339). *Graesse* (VI[1] 20).

**Ranzovius**, Henricus.

Henrici Ranzovii prodvcis Cimbrici diarivm sive calendarivm romanvm oeconomicvm, ecclesiasticvm, astronomicvm, et fere perpetvvm. ....Wittebergae. Excudebat Christophorus Axinus. Anno CIↃIↃXCIII. Small 4to. (8) ff. 413, (3) pp. Contains "De prognosticis mutationum aeriarum. De ventis. Tabula mutationum aëriarum. Collecta varia ex rebus variis mutationū praesagia." *Graesse* (VI *i* 24).

**Rao**, Cesare.

I meteori di Cesare Rao di Alessano città di Terra d'Otranto. I qvali contengono qvanto intorno a tal materia si puo desiderare. Ridotti a tanta ageuolezza, che da qual si voglia, ogni poco ne gli studi essercitato, potranno facilmente e con prestezza esser intesti......In Venetia, appresso Giouanni Varisco & Compagni. MDLXXXII. 4to. (16) 167 ff. [In fine :] MDLXXXI.

Scarce. *Graesse* (VI[1] 25). *Riccardi* (II 342).

**Rasch**, Johann.

Practica auff das groszwunder Schaltjar. 1588. Gestellt durch Johann Rasch zu Wienn......Anno MDLXXXVIII......4to. (19) ff.—See my book "Meteorologische Volksbücher" (p. 33), where I have analyzed the meteorological contents of this "Practica." *Graesse* (VI *i* 35).

**Reael**, Laurens.

Observatien of Ondervindingen aen de Magneetsteen en de Magnetische kracht der Aerde; door den Heer Laurens Reael......Quibus adjunctae sunt celeberrimi professoris D. Casparis Barlaei cavsae et rationes observationvm earvndem magneticarvm. t'Amsteldam. By Lodewijck Spillebout...... 1651. Small 8vo. (8) ff., 91 pp. Woodcuts.

Scarce. *Bierens de Haan.*

**Reinzer**, Franz.

1. Meteorologia philosophico-politica, in duodecim dissertationes per quaestiones meteorologicas & conclusiones politicas divisa, appositisque symbolis illustrata: honori Avgvsti Romanorvm Regis Josephi I. inscripta ab illustrissimo domino Joanne Bernardo Caelestino, Sac. Rom. Imp. Comite à Rüdern, Austriaco Manseensi......praeside R. P. Francisco Reinzer, e Soc. Jesu .....Anno MDCXCVII ...... Avgvstae Vindelicorvm, Typis Antonii Nepperschmidii......Fol. (4) ff., 297, (5) pp. With many emblematic illustrations and a frontispiece.

**Reinzer**, Franz—Continued.

2. [The same work]: MDCXCVIII. Avgvstae Vindelicorvm, Impensis Ieremiae Wolfii......Fol. (4) ff. 297, (5) pp. With the same illustrations.

A curious and typical sample of emblematic meteorology. I possess two other editions of this work, one in Latin, 1709, and the other in German, 1712.

**Resta**, Francesco.

Meteorologia de igneis aereis aqveisq. corporibus avthore P. Francisco Resta a Talleacotio Cler. Reg. Minor. Romae, apud Franciscum Monetam. An. MDCXLIIII. 4to. (6) ff., 952 pp. (17) ff. Engraved title.

**Rhodius**, Ambrosius. [**Rhode**.]

Optica Ambrosii Rhodii, Kembergensis, ...... cui additus est tractatus de crepusculis. Wittebergae, typis Laurentij Seuberlich......Anno 1611. 8vo. (17) ff., 418, 63 pp. *Hellmann* (406.)

**Reynman**, Leonhard. [Reyman, Rinman, Rynman.]

Von warer erkanntnuss des wetters. Also das ein yeder er sey gelert oder vngelert durch alle natürliche anzaigung die änndrūg des wetters aygentlich vn augenscheinlich erkennen mag etc. [Woodcut.] 4to. (8) ff., last blank. [In fine:] ...... Gedruckt zu München durch Hannssen Schobsser. Im dem jare......MCCCCC. vñ jm zehenden jare......

Unique copy of this early edition of the German meteorological chapbook "Wetterbüchlein," reproduced in facsimile in No. 1 of a series of reprints I have begun to issue under the title: "Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus." (Berlin. A. Asher & Co. 1893. 4to.) In the introduction to this reprint are enumerated all the known 17 editions of the "Wetterbüchlein." I possess three other editions, without date, but probably published about 1510 and 1520 (numbered 13, 15, and 16 in the above-named introduction.) *Graesse* (VI*i* 99). *Hellmann* (403).

**Riccioli**, Giambattista.

Geographiae et hydrographiae reformatae nuper recognitae, & auctae, libri duodecim. Avctore R. P. Io. Baptista Ricciolio Ferrariensi Societatis Iesv......Venetiis, Typis Ioannis La Noù, MDCLXXII......Large folio. (8) ff. 691 pp.

Second edition (first issued at Bologna in 1661) of this esteemed encyclopaedic work. The author deals *inter alia* with the height of the clouds, devising a simple trigonometrical method of measuring it, with the magnetic needle, giving a large list of all known values of declination, with the winds, storms, etc. *Brunet* (IV 1277). *Graesse* (VI*i* 109). *Riccardi* (II 370.)

**Richus**, Leonardus.

Leonardi Richi Lvcensis in falsvm dilvvii prognosticon opvscvlvm.

Diluuii qui falsa times portenta futuri:

Me lege: causa tibi nulla timoris erit.

Small 4to. (16) ff. [In fine:] Impressum Luce per Saluatorem Sucham Florentinum Anno a Natiuitate Christi MDXXIII. Mense Nouembris.

Scarce. For the subject see the note to "*Niphus.*"

**Scheggius**, Jacobus.

Iacobi Scheggij Schorndorffensis in reliqvos natvralivm Aristotelis libros commentaria plane philosophica, nunc primum in lucem edita: videlicet...... meteoron lib. iiii......Basileae, per Ioannem Heruagium, Anno 1550. Mense Martio. Fol. (8) ff., 539, (29) pp.

**Schmidt**, Johann Andreas.

Lunam in cruce visam d. 30. Dec. h. 1 p. m. n. 1680......exponent praeses M. Jo. Andr. Schmidt, adjunctus & Paulus Pater respondens......MDCXIXC. Jenae. Typis Johannis Nisl. 4to (1) f., 58 pp. 2 plates. *Hellmann* (433).

**Schott**, Caspar.

1. P. Gasparis Schotti Regiscuriani e societate Jesu, olim in Panormitano Siciliae, nunc in Herbipolitano Franconiae gymnasio ejusdem societatis Jesu matheseos professoris, Technica curiosa, sive mirabilia artis, libris xii comprehensa, quibus varia experimenta......proponuntur......Sumptibus Johannis Andreae Endteri......Anno MDCLXIV......4to. (20) ff., 1044 pp., (8) ff.

   Frontispiece and many plates. Contains many documents relative to the invention of the barometer, and the earliest account of Otto von Guericke's experiments.

2. P. Gasparis Schotti......Physica curiosa sive mirabilia naturae et artis libris xii comprehensa, quibus pleraque, qua de angelis......meteoris......rara circumferuntur......Editio tertia......Herbipoli, excudit Jobus Hertz......Anno MDCXCVII. 4to. (18) ff., 1389, (21) pp. Frontispiece and many plates.

   The 11th book: Miribilia meteororum. *Brunet* (V 219). *Graesse* (VI*i* 314). *Hellmann* (624).

**Schwenter**, Daniel.

Deliciae physico-mathematicae oder mathemat. vnd philosophische Erquickstunden, darinnen sechshundert drey vnd sechzig schöne, liebliche vnd annehmliche Kunststücklein ...... verzeichnet worden ...... durch M. Danielem Schwenterum..... Nürnberg, in Verlegung Jeremiae Dümlers. A°. MDCXXXVI. 4to. (6) ff., 574 pp., (1) f. with many woodcuts and a frontispiece.

Delitiae mathematicae et physicae. Der mathematischen und philosophischen Erquickstunden zweyter Theil; bestehend in fünffhundert nutzlichen und lustigen Kunstfragen ...... zusammen getragen durch Georg Philip Harsdörffern .....Nürnberg, gedruckt und verlegt bey Jeremia Dümlern. Im Jahr MDCLI. 4to. (12) ff. 616 pp., woodcuts and frontispiece.

The chapter in vol. I, p. 455, dealing with the thermometer ("Ein Instrument zu machen, damit die Graden der Hitz und Kälte zu messen") is taken from Leurechon's work.

**Seneca**, Lucius Annaeus.

Lucii Annei Senecae philosophi clarissimi, natvralium quaestionum ad Lucilium libri septem, à Matthaeo Fortunato, Erasmo Roterodamo, & Lodoico Strebaeo diligentissime recogniti. Parisiis ex officina Michaëlis Vascosani, in via quae est ad diuum Iacobum, sub fontis insigni. MDXL. Large 8vo. (104) ff.

First good and corrected edition of Seneca's treatise on natural philosophy, of which but very few separate editions exist. Except Plinius, there is no other Roman philosopher who devotes so much attention to the "meteors" as Seneca. A good modern edition with commentaries is that by G. D. Koeler, Gottingae, 1819. 8vo. 717 pp. *Brunet* (V 275). *Graesse* (VI*i* 346).

**Sennert**, Daniel.

Danielis Sennerti D. Vratislaviensis epitome naturalis scientiae. Editio vltima. Amstelaedami. Sumptibus Ioannis Ravesteinii. A°. 1651. 12mo. (7) ff. 679, (23) pp.

Deals in 10 chapters with meteorology in the same order as Aristotle.

**Seville**, I. de.

Le compost manvel calendier et almanach perpetvel recueilli & reformé selon le retranchement des dix iours......Reueu corrige & augmente outre les precedentes impressions. Par I. de Seville, dit le Soucy medecin mathematicien. A Roven, chez Thomas Mallard......MDXCV. 4to. (4) ff. 161 pp. 1 fold. table. With woodcuts in the text. On pp. 49–58: "L'Almanach perpetuel pour la temperature du temps"; pp. 62–69: "Comment on peut prognostiquer des tempestes & orages par signes......"

Scarce. Original edition issued in 1587. *Brunet* (V 326). *Graesse* (VI*i* 378).

**Simplicissimus.** [Hans Jacob Christoffel **von Grimmelshausen.**]

Des abenteurlichen Simplicissimi ewig-währender Calender worinnen ohne die ordentliche Verzeichnus der unzehlbar vieler heiligen Täge auch unterschiedliche curiose Discursen von der Astronomia......und aus fleissiger observation künfftig Gewitter......vorzusagen......In Nürnberg. Verlegt und zu finden bey Wolf Eberhard Felszecker. 4to. 234 pp. Frontispiece. [In fine :] Gedruckt zu Altenburg, bey Georg Conrad Rügern, im Jahr 1677. *Graesse* (VI*i* 411).

**Sinclair,** George.

Georgii Sinclari quondam in vniversitate Glasguensi philosophiae professoris, Scoto-Lothiani, ars nova et magna gravitatis et levitatis. Sive dialogorum philosophicorum libri sex de aeris vera ac reali gravitate, &c., quibus accessere de instrumentis hydragogicis libri duo, de hygroscopio, & chronoscopio seu pendulo liber unus, nec non palladis gymnasium......Roterodami, ex officina Arnoldi Leers Junioris. CIƆIƆCLXIX. 4to. (14) ff. 625 (21) pp.

Important for the history of the barometer. Scarce. *Graesse* (VI*i* 416). *Lowndes* (Pt. ix, 2404).

**Smith,** John.

Horological disquisitions concerning the nature of time......By John Smith, C. M. To which is added, the best rules for the ordering and use both of the quick-silver and spirit weather-glasses......London : Printed for Richard Cumberland......1694. Small 8vo. (2) ff. 92 pp. 1 fold. table. The meteorological part occupies pp. 61 to 89.

**Stamm,** Peter.

I. N. J. Meteororum emphaticorum reginam iridem ex physicis praeses M. Petrus Stamm Halberstadensis, respondente Carolo Friderico Zandero, Berlinate disputatione publica......ad ventilandam sistet......1669......Wittebergae, praelo Johannis Haken. 4to. (8) ff. *Hellmann* (475).

**Stanhufius,** Michael.

De meteoris libri dvo, qvorvm prior tradit de aethere, et elementis. Posterior complectitur omnium fere meteororum prolixam explicationem. Recitantur etiam passim Aristotelis, Plinij & aliorum philosophorum iudicia & opiniones, conscripti & editi a M. Michaele Stanhvfio Franco. Vitebergae Anno MDLXII. Small 8vo. (168) ff.

Original edition of a scarce treatise on meteorology. I possess also another edition: [The same title]. Vitebergae. Anno MDLXXVIII. Small 8vo. (168) ff. *Hellmann* (475).

**Stœltzlin,** Bonifacius.

Geistliches Donner- und Wetterbüchlein. Das ist: einfältige Erinnerung vom Donner, Blitz, Stral, Hagel und schädlichen Wettern: wie dieselbige anzusehen und zu betrachten: wie man sich auch darbey christlich verhalten sol......Durch M. Bonifacium Stöltzlin, Ulmens......Zum andernmal gedruckt zu Vlm, Verlegt durch Matthaeum Vogt......1654. Small 12mo. (1) f. 422 pp. (5) ff. Frontispiece.

**Sturm,** Johann Christoph.

1. Collegium experimentale, sive curiosum, in quo primaria hujus seculi inventa & experimenta physico-mathematica, speciatim campanae vrinatoriae, camerae obscurae, tubi Torricelliani, seu baroscopii, antliae pneumaticae, thermometrorvm, hygroscopiorum......exhibita......Johannes Christophorus Sturmius, Phil. M. Mathem. ac. Phys. in incluta Altdorffina P. P. & h. t. univer. Rector. Norimbergae, sumtibus Wolfgangi Mauritii Endteri & Johannis Andreae Endteri Haeredum. Anno MDCLXXVI. 4to. (12) ff. 168, 122 pp. (6) ff. With plates and many woodcuts in the text.

**Sturm**, Johann Christoph—Continued.

Collegii experimentalis sive curiosi pars secunda......Norimbergae......Anno MDCLXXXV. 4to. (10) ff. 256 pp. With many woodcuts in the text.

Very important for the history of the principal meteorological instruments. I possess also the second edition, issued at Nürnberg, 1701–1715, in 2 volumes.

2. θαυμαντιαδος θαυμασια sive iridis admiranda sub rationis accuratius examen revocata, eruditorumque ventilationi publicae in alma Altdorffina universitate exposita sub praesidio M. Joh. Christophori Sturmii......à Christophoro Theophilo Volcamero. P. N. Noribergae, apud Wolfangum Mauritium Endterum. Anno MDCXCIX. 4to. (1) f. 185 pp. *Graesse* (VI[1] 517). *Hellmann* (486).

**Tarde**, Jean.

Les vsages du qvadrant a l'esgville aymantee. Divisé en devx livres......Par Iean Tarde, chanoine theologal de Sarlat. A Paris. Chez Iean Gesselin ......MDCXXIII. 4to. (6) ff. 120 pp. Woodcuts.

**Tartaglia**, Niccolo.

Regola generale di solevare ogni fondata naue & nauilii con ragione. 4to. (4) (32) ff. [In fine:] In Vinegia, per Curtio Troiano dei Nauò. MDLXII.

Contains a pretty large chapter: "Segni delle mutationi dell'aria," i. e., a collection of weather prognostics. *Brunet* (V 660). *Graesse* (VI[2] 29). *Riccardi* (II 496).

**Telesius**, Bernardinus. [**Telesio.**]

Bernardini Telesii Consentini de his, quae in aëre fiunt; & de terraemotibus, liber vnicus ...... Neapoli, Apud Josephum Cacchium. Anno MDLXX. 4to. 14, (1) ff. (last blank.)

Scarce little treatise. *Graesse* (VI[2] 47). *Riccardi* (II 512).

**Theophrastus.**

Theophrasti Eresii, peripateticorum post Aristotelem principis, pleraque antehac Latine nunquam, nunc Graece & Latine simul edita. Interpretibus, Daniele Fvrlano Cretensi, Adriano Tvrnebo. Accesserunt, liber de innato spiritu, Aristoteli attributus, & Danielis Fvrlani vberes ad omnia commentarii. Ex bibliotheca Ioan. Vincentii Pinelli Hanoviae, Typis Wechelianis, apud Claudium Marnium & haeredes Ioannis Aubrii. MDCV. Fol. (4) ff. 397, (3) pp.

Scarce edition. Chapters II to V contain "De signis pluviarum. De signis ventorum. De signis tempestatis. De signis serenitatis," with Furlano's interpretation. *Brunet* (V 797). *Graesse* (VI[2] 124).

[**Thunderstorm.**]

Petit traitez dv tonnerre, esclair, fovdre, gresle, & tremblement de terre: Auquel est aussi parlé des sorciers, du pouuoir qu'ils ont, & de celui qu'ils, cuident auoir. Pseavme CXV. Deuant le Dieu de Iacob, quand il veut, terre tremble, craintiue. Pour Iaques Chouët. MDXCII. Small 8vo. 126 pp. (1) f. Scarce.

**Titelmann**, Franz.

De rervm natvralivm consideratione libri duodecim autore Francisco Titelmanno Hassellensi, recens iam ab innumeris mendis ac multis superuacaneis diligenter repurgati. Cum indice rerum copioso. Coloniae ex officina Melchioris Nouesiani. Anno MDXLIIII. Small 8vo. (20), 288 ff. An old treatise on natural philosophy (of course Aristotelean). Liber vi "De meteorologicis impressionibus."

**Vallemont**, Pierre le Lorrain, abbé de.

1. La physique occulte ou traité de la baguette divinatoire, et de son utilité pour la découverte des sources d'eau des miniéres, des tresors cachez, des voleurs & des meurtriers fugitifs. Avec les principes qui expliquent les phénomènes les plus obscurs de la nature. Par M. L. L. de Vallemont, prêtre, & docteur en theologie. A Paris, chez Jean Anisson...... MDCXCIII......12mo. (15) ff. 609 pp. With woodcuts. Original edition.
2. [The same title]. Augmenté en cette edition, d'un traité de la connoissance des causes magnetiques des cures sympathiques des transplantations & comment agissent les philtres. Par an curieux de la nature. Augmentée de plusieurs pieces. A Paris, chez Jean Boudot......MDCXCVI. (8) ff. 422, 34 pp. (4) ff. With frontispiece and plates.

Curious book, dealing also with meteorological and magnetical instruments. *Brunet* (V 1060). *Graesse* (VI² 251).

**Verbiest**, Ferdinand.

Astronomia europaea svb imperatore tartaro sinico Câm Hy appellato ex umbra in lucem revocata a R. P. Ferdinando Verbiest Flandro-Belga e Societate Jesu academiae astronomicae in regia Pekinensi praefecto......Dilingae typis & sumptibus Joannis Caspari Bencard......Anno MDCLXXXVII. 4to. (4) ff. 126 (2) pp. One fold. plate.

Caput xxvii: Meteorologia. Verbiest made a thermometer from Chinese glass for the emperor about 1665, and later an hygrometer. *Graesse* (VI² 279).

**Vergilius**, Polydorus.

Polydori Vergilii Vrbinatis de inventoribvs rerum libri viii et de prodigiis libri iii. Cum indicibus locupletissimis. Amstelodami. Apud Danielem Elzevirivm, CIƆIƆCLXXI. Small 12mo. (20) ff. 511 pp. (3) ff. 100 pp. (46) ff.

Esteemed edition. I possess another edition, issued at Bâle, per Thomum Guarinum, 1563, and the translation into German by Marcus Tatius, published at Franckfurt in 1615. 8vo. *Brunet* (V 1136). *Graesse* (VI² 283).

**Vicomercatus**, Franciscus. [**Vimercati**, Francesco.]

Francisci Vicomercati Mediolanensis in qvatvor libros Aristotelis meteorologicorum commentarij et eorumdem librorum è graeco in latinum per eundem conuersio. Ad Carolvm a Lotharingia cardinalem. Venetiis, MDLXV. Ex officina Dominici Guerrei et Io. Baptistae fratrum. Fol. (6) 217, (1) ff. With woodcuts in the text.

The first edition was published at Paris in 1556. The author gives at first the Greek text, then his Latin translation, and thereafter his prolix commentaries. *Riccardi* (II 601).

**Vieri**, Francesco de'.

Trattato di M. Francesco de'Vieri cognominato il Verino secondo cittadino Fiorentino, nel qvale si contengono i tre primi libri delle metheore. Nvovamente ristampati, & da lui ricorretti con l'aggiunta del quarto libro ...... In Fiorenza. Appresso Giorgio Marescotti. MDLXXXII. Small 8vo. (8) ff. 424 pp. (8) ff.

Contains also the fourth book of Aristotle's meteorology. Original edition issued in 1573. *Graesse* (VI² 311). *Riccardi* (II 599).

**Vitellio.**

Vitellionis mathematici doctissimi περὶ ὀπτικῆς, id est de natura, ratione, & proiectione radiorum uisus, luminum, colorum atq; formarum, quam uulgo Perspectiuam uocant, libri x......Nunc primum opera mathematicor. praestantiss. dd. Georgij Tanstetter & Petri Apiani in lucem aedita. Norim-

**Vitellio**—Continued.

bergae apud Io. Petreium. Anno MDXXXV. Fol. (4), 297 ff. With many woodcuts in the text. Title in black and red.

Scarce original edition; for another, see *Alhazen*. The last chapters deal largely with the rainbow.

**Vitruvius.**

Archittetvra con il svo cõmento et figvre. Vetrvvio in volgar lingua raportato per M. Gianbatista Caporali di Pervgia. Fol. (3), 131 ff. [In fine:] Stampato in Perugia, nella stamperia del conte Iano Bigazzini, il di primo d'Aprile. l'Anno MDXXXVI. With frontispiece and many woodcuts in the text.

Scarce. The comments (ff. 32 to 39) treat extensively of the winds; on p. 34 a very interesting sketch of the "Tower of Winds," made at Athens by Andronicus Cyrrhestes. For more details see my paper "Die Anfänge der meteorologischen Beobachtungen und Instrumente" (Himmel und Erde. Vol. ii. 1890.) *Brunet* (V 1326). *Graesse* (VI² 376). *Riccardi* (II 600).

**Vossius**, Isaac.

1. Isaac Vossi de motu marium et ventorum liber. Hagae-Comitis, Ex typographia Adriani Vlacq. Anno MDCLXIII. 4to. (4) ff. 123 pp. (2) ff.
2. Isaacus Vossius de Nili et aliorum fluminum origine. Hagae-Comitis. Ex typographia Adriani Vlacq. MDCLXVI. 4to. (8) ff. 76 pp. 2 maps, and woodcuts in the text.

*Bierens de Haan.* Deals with the climate, especially with the rainfall of the torrid zone.

**Wagner**, Johann Jakob.

Historia naturalis Helvetiae curiosa, in vii. sectiones compendiose digesta. Authore Joh. Jacobo Wagnero, Med. Doct. Tiguri, Impensis Joh. Henrici Lindinneri, Bibliopeg. MDCLXXX. 12mo. (12) ff. 390, (28) pp.

Deals with the climate of Switzerland. Sectio vii. De Meteoris.

**Zahn**, Johnn.

Specula physico-mathematico-historica notabilium ac mirabilium sciendorum, in qua mundi mirabilis oeconomia, nec non mirifice amplus, et magnificus ejusdem abdite reconditus......thesaurus curiosis omnibus cosmosophis inspectandus proponitur...... quo universae naturae majestas in triplici mundo coelesti, aereo & terrestri......ostenditur......Authore Joanne Zahn ...... Norimbergae, sumptibus Joannis Christophori Lochner ...... An. MDCXCVI. Large fol. (26) ff. 448 pp. (4) ff. Frontispiece. Tomus II; Frontispiece. (8) ff. 460 pp. (4) ff. Frontispiece. Tomus III: (5) ff. 248 pp. (4) ff. With many figures in the text and large fold. plates.

Voluminous encyclopædic work, embracing the sciences. "Aero-scopia," "Anemo-scopia," "Meteoro-scopia," on pp. 308 to 448 of vol. 1. *Brunet* (V 1519). *Graesse* (VI² 503.) *Hellmann* (544).

**Zuccolo**, Vitale.

Dialogo delle cose meteorologiche. Di D. Vitale Zvccolo Padoano Theologo, e Monaco Camaldolense. In cvi si dichiarano tvtte le cose marauigliose, che si generano nell'aere, & alcune mirabili proprietà de' fonti, fiumi, e mari, secondo la dottrina d'Aristotele con le opinioni d'altri illustri scrittori......In Venetia, MDXC. Appresso Paolo Megietti. Small 4to. (4) ff. 165 pp. *Riccardi* (II 672).

## II. SUBJECT INDEX.

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## III.—CHRONOLOGICAL INDEX.

(Year of printing.)

**1626–1650**: Bacon. 1, 2. Blancanus, 2. Casati. Crusius. Elephantutius. Fludd, 2. Gilbert, 2, 3. Grandamicus. [Kalender.] Kircher, 1, 2. Leurechon, 1. 2, 3, 5. Lilly. Morisot. Naiera. Petavius. Petit. Resta. Schwenter.

**1651–1675**: Accademia del Cimento. Argoli. Bakius, 1, 2, 3, 4, 5. Bartholinus, 1, 2. Baudisius. Benincasa. Berger. Berigardus. Bleidner. Bohun. Borelli, 1. Castelli, 1, 2. Claramontius. Dingley. Descartes. Dobrzenski. Du Hamel. Fournier. Fromondus. Götz. Grimaldi. Guericke. Hobbes. Hoen. Hooke. Ingegneri. [Kalender.] Kircher, 2. Lana. Leotaud. Leurechon, 4. Linus. Monconys. Morin. Papa, 1. Pascal, 1, 2. Perrault. Piso. Proclus, 2. Reael. Riccioli. Schott, 1. Sennert. Sinclair. Stamm. Stültzlin. Vergilius. Vossius, 1, 2.

**1676–1700**: Accademia del Cimento, 3, 4. [Almanacs.] Amontons. Bartoli. Brerewood. Borelli, 2. Camerarius. Cock. Dalencé, 1, 2, 3, 4. Francisci. Gouye. Husch. [Kalender.] Kircher, 3. Le Grand. [Memoirs.] Montanari, 1, 2, 3. Oudenhoven. Papa, 2. Pascal, 3. Pasch. Plot. Ramazzini. Reinzer. Schmidt. Schott, 2. Simplicissimus. Smith. Sturm, 1, 2. Vallemont, 1, 2. Verbiest. Wagner. Zahn.

## SECTION V.

# AGRICULTURAL METEOROLOGY.

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### 1.—METEOROLOGICAL OBSERVATIONS CONSIDERED WITH SPECIAL REFERENCE TO INFLUENCE ON VEGETATION.

Prof. Dr. PAUL SCHREIBER.

The ultimate aim of all meteorological observations is the advancement of meteorology as a science; and this depends solely on our progress in the comprehension of the "laws of motion," which govern the immense mechanism of the atmosphere, and their application to the many problems of human existence. Nevertheless, we must not confine our attention to this one great aim.

The time is past when science could separate itself from the busy world and find its proper development behind the walls of convents. To-day we must enter fully into practical life and actively participate in its duties, in order to grasp the problems whose solution is the true mission of science—not for abstract science's sake, but also for the benefit of mankind in its frequently bitter struggle for existence.

Thus, every, or rather most, central meteorological institutions will eventually be called upon to undertake, jointly with the pursuit of purely scientific investigation, the practical application of some of the results, to an extent that will either be prescribed by the government or demanded by the agricultural conditions of each country. In countries where agriculture is the chief occupation of the people, meteorology will have to serve the interests of the husbandman; for agriculture, above all other occupations, is so directly and universally dependent on the weather that it must necessarily derive the most of the benefit resulting from the progress of our labors. On the weather depend the beginning and progress of tillage in the spring; the development, growth, blooming, and ripening of vegetation; and, in a great measure, the husbandman's reward in successfully sheltering his harvest.

The growth of vegetation requires heat, water, and sunshine; but of each the proper measure, as every excess or deficiency acts injuriously. It should, therefore, be the object of our investigations to determine how much of heat, water, and sunshine is required by different plants, and how these influential factors are to be distributed

during the various phases of plant life. Frequent observations of the temperature, both above and below the ground, will be necessary to enable us to compute the available supply of heat at any time.

Similar observations are required as to the available store of moisture. It will hardly be necessary to add that its increase by rain and snow is to be accurately determined. But ground and plants are also watered in other ways. Dew, rime, hoar frost, and especially fog, are more important factors in many climates and on elevated regions than is generally believed. As regards vegetation it is less the increase than the continuance or permanence of moisture, that is of importance. It is more especially a question of the quantity which is hygroscopically stored in the greater or smaller cavities below the surface, or which covers the ground in the form of snow. Accurate statistics of these quantities will be of the utmost importance in studying the reciprocal effects of weather conditions and vegetation. I feel justified in saying that too little attention has heretofore been given to this subject.

In this connection a close investigation of the processes of evaporation is also necessary. Our information concerning the duration and power of sunshine is increasing so rapidly that we may hope for early and important additions to our knowledge concerning these elements of our investigations. If our labors in this direction are to be of practical value to the husbandman, they must include careful notations of the successive phases of plant life or, at least, of the main phases of growth—the so-called phenologic observations. If, in this manner, we discover the laws governing each separate phase or phenomenon, and from them the joint result of their reciprocal influences, our object will have been accomplished.

Besides collecting information bearing directly on vegetation, we must not, however, forget other subjects of inquiry whose connection is of a less direct character. When our investigations have shown that there is in a given region either an excess or a deficiency of heat, moisture, or sunshine, the question will be asked whether it is within the limited power of man to provide a remedy. To supply heat where it is lacking or to dispose of a surplus by utilizing it elsewhere are problems the successful solution of which is indeed very doubtful.

It is different as regards water. Here man's exertion can make itself felt, though it would be a waste of time and labor to further continue attempts at artificial rain production. The possibility of causing a condensation of the vapor in the air, so that it will be precipitated in the form of rain, must be admitted from a theoretical point of view. But this will ever remain a more or less costly experiment, without any practical useful results, as may be inferred from a simple consideration. Whatever may be the atmospheric condi-

tion in the regions where it is desired to produce rain, it will always be necessary to divert the masses of air flowing over them from those channels which are the result of the great movements taking place over the earth's surface; or in calm regions, to draw winds from the ocean, and eventually transform them into vertical components flowing upward. But as the air rarely contains 1 per cent of its entire weight in vapor, it follows that a dead weight of about 99 per cent will have to be moved or diverted at the same time. All of which implies such an enormous waste of mechanical labor that the end in view can never be attained in that way or, at best, only in very rare cases.

On the other hand the transport of water is practicable almost everywhere. The transfer of water from higher to lower regions, by means of artificial conduits, is coming more and more into use, and seldom offers other difficulties than the construction of the conduits. To a less extent, but still quite frequently, water is pumped from wells or rivers into reservoirs of sufficient elevation to allow of its distribution to points where it may be needed. A minute portion of the enormous mechanical power inherent to air in motion is here utilized by the employment of wind mills. This method has every prospect of success, and deserves to become more and more general. The utilization of this form of solar heat, in connection with the means of storage provided by mechanical or electrical contrivances, has surely a great future before it.

But the more man interferes with or encroaches upon natural conditions the greater is the possibility that the community of interests, which in the beginning induced consumers of water to unite in the construction of conduits or waterworks of any description, will later on be transformed into an antagonism of separate interests. To guard against this from the beginning, as well as to prevent the failure of such enterprises, a close observation of the operations of nature is necessary. In this connection we must not only carefully determine what quantity of water reaches the earth's surface in various forms, but we must observe its upward and downward course as well. Upward, it goes into the air by evaporation; downward, it either flows on the surface, in creeks or rivers, toward the ocean, or it penetrates into the depths of the ground, to follow a course that is determined by the various conditions existing there. It is our task to follow and measure these several processes.

Observations of the amount of water carried in rivers serve the additional purpose of supplementing our measurements of the precipitation. How often do we find the sources of large streams in regions where, according to our rain charts, there is a decided lack of precipitation. We read of enormous rises and floods of such rivers when the snows are melting, and can not comprehend where all this water

comes from. On this point, as well as concerning the excessive quantities of water that occasionally fall during thunderstorms, we can only reach a clear understanding by watching the behavior of the rivers.

The interests of vegetation, therefore, require a careful investigation of all problems relating to solar heat and water; but we must also take care to bring these investigations into connection with our observations of vegetation itself. Not only must we insist upon comprehensive methods of observation, but also upon the systematic study and digestion of the collected data. Our libraries annually receive numerous volumes which, filled more or less with figures, contain a rich store of unworked observations. But we have only a few works in which we meet with a comprehensive digestion and review of this immense accumulation of crude material. Where will this end if the task is not undertaken at an early date? It should be our special endeavor to devise methods of representing large series of figures by mathematical expressions. Periodical occurrences, such as the daily or annual variations in meteorological phenomena, must, whenever possible, be expressed by "Bessel's formula" (harmonic analysis). At the same time all superfluous minuteness of computation must be avoided, as the object in view is to express the essential features of phenomena in the fewest possible terms, not exceeding three, if practicable; otherwise, serial evolution will serve no useful purpose. To replace a number of observed values with an equal number of coefficients in a series of sines and cosines would, of course, be extremely superfluous and bootless.

I may be permitted, in this connection, to invite the attention of the Congress to my investigations of the nature of Bessel's formula, etc. ("Nova Acta" of the Imperial Leop. Carol. German Academy of Natural Philosophers. Vol. VIII, No. 3, Halle, 1892.)

In combining the observations of a system of stations, additional calculations are necessary, in connection with which we must get rid of the contingencies of local conditions. It is required to represent the results of a system of stations as "functions" of their position on our globe. If, therefore, $y$ denotes any given meteorological element, either the simple values of simultaneous observations, or the means of the observations for any given period, and $\varphi$, $\lambda$, $h$ are the corresponding latitude, longitude, and elevation above sea of a place, then is

$$y = f(h \varphi \lambda)$$

It can not be doubted that the form of this function will generally be very complicated, and that it will be advisable, therefore, to determine it first for small districts. This done, the next step will be the combination of the single formulas. In the derivation of such formulas two methods can be employed. According to the first, we

lay down theoretically certain principles and endeavor to clothe them in formulas. According to the second, use is made of the serial form, as

$$y = y_0 + bh + c\psi + d\lambda + eh^2 + f\psi^2 + g\lambda^2 + \ldots\ldots$$

endeavoring to determine the values of the coefficients from the observations, and then see how these observations are expressed by the series.

For smaller districts, which are sufficiently remote from those points at which the function reaches an extreme value, a series of only a few terms will generally suffice. We may first of all experiment with the form,

$$y = y_0 + bh + c\psi + d\lambda$$

which for

$$\psi = \psi_0 + \Delta\psi, \quad \lambda = \lambda_0 + \Delta\lambda$$

and

$$a = y_0 + c\psi_0 + d\lambda_0$$

changes into the form,

$$y = a + bh + c\Delta\psi + d\Delta\lambda$$

In most cases it will be found that the first two terms exceed the last two enough to permit us to neglect the latter, i. e., to include them in the accidental errors $\delta$, when the object is to determine the constants $a$ and $b$ by means of the method of least squares, from $n$ observed values $y_1, y_2, y_3, \ldots\ldots y_n$, and for $n$ altitudes $h_1, h_2, h_3, \ldots\ldots h_n$, according to the equations of condition

$$\begin{aligned} y_1 &= a + bh_1 + \delta_1 \\ y_2 &= a + bh_2 + \delta_2 \\ &\cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ y_n &= a + bh_n + \delta_n \end{aligned}$$

But before undertaking such complicated calculations it will always be advisable to satisfy ourselves, by means of graphic constructions, whether the fundamental form of equation is expressed in these equations.

Within the past few years I have caused the compilation of the principal results of the observations made since 1864 at 15 stations in Saxony, representing elevations of from 120 to 930 meters. The lustral means were found, and then the means for the whole period from 1864 to 1890. All monthly and annual means thus found for periods of five and more years were represented according to the equation $y = a + bh$. I have, therefore, given to that equation the name of fundamental equation, and I further call $a$ the fundamental value, and $b$ the coefficient of elevation.

The mean values themselves I have published in the second number of the "Climate of Saxony," and the results of the calculations under present consideration are intended for the third number of

that series. I may be permitted to present here a few of the principal results. I will give, in the first place, the coefficients of the fundamental equations for the annual means, together with their mean errors ($\mu$). The coefficient of altitude is for each 100 meters. For the general mean temperature we have

$$a = 9.29^\circ \text{ C.} \pm 0.22^\circ;\ b = -0.574^\circ \pm 0.045^\circ;\ \mu = \pm 0.43^\circ.$$

On the other hand, for the means of the 2 p. m. temperatures

$$a = 12.63^\circ \pm 0.22^\circ;\ b = -0.656^\circ \pm 0.045^\circ;\ \mu = \pm 0.43^\circ.$$

And for the minima

$$a = 5.46^\circ \pm 0.35^\circ;\ b = -0.579^\circ \pm 0.070^\circ;\ \mu = \pm 0.67^\circ.$$

The means derived from the periodical observations of twenty-seven years are, according to the above, represented by the fundamental equations as having a mean error of $\pm 0.43^\circ$. The mean uncertainty of the fundamental values is $\pm 0.2^\circ$, and that of the coefficients of altitude, $\pm 0.045^\circ$ per 100 meters. A greater uncertainty attaches to the means of the minimum temperatures.

As regards the climatic conditions of a locality the diurnal period of the temperature is, in addition to the mean temperatures, of the utmost importance. A representation of the equation for this diurnal period is obtained from the equations for the temperatures $2^h\,p$ ($t_2$) and for the minimum temperatures ($t_m$).

It follows from

$$t_2 = 12.63 - 0.656h \text{ and } t_m = 5.46 - 0.579h,$$

that

$$t_2 - t_m = 7.17 - 0.077h.$$

It will be seen from this that the range of oscillation is diminished 0.077° for each 100 meters additional height.

For the 6 a. m., 2 p. m., and 10 p. m. observations we obtained for the fifteen years, 1866 to 1890

$$t_2 - t_6 = 5.81 - 0.193h;\ \mu = \pm 0.63;\ \mu_a = \pm 0.33;\ \mu_b = \pm 0.066$$
$$t_2 - t_{10} = 4.26 - 0.042h;\ \quad 0.59;\ \quad 0.31;\ \quad 0.061$$

The combination of these equations with that for $t_2$ (the latter derived from the period 1864 to 1890) gives

$$t_6 = 6.82 - 0.463h$$
$$t_2 = 12.63 - 0.656h$$
$$t_{10} = 8.37 - 0.614h$$

Here we are impressed by the smallness of the coefficient of altitude for the hour of 6 a. m. It follows that, immediately after the time of the minimum temperature, and during the first hours of the rise, there must exist a remarkable uniformity in the vertical distribution of temperature. Of interest also is the equation

$$t_{10} - t_6 = 1.55 - 0.151h.$$

This shows that at elevations below 1,000 meters $t_{10}$ is greater than

$t_6$; in other words, that the evenings are warmer than the morning hours. At elevations of 1,000 meters equal temperatures prevail at 6 a. m. and 10 p. m.; but higher up the evenings are no doubt cooler.

The equations for vapor tension were deduced in the same way, resulting in (millimeters)

| | | | |
|---|---|---|---|
| $s = 6.93 - 0.146h$, | $\mu = \pm 0.18$, | $\mu_a = \pm 0.09$, | $\mu_b = \pm\ 0.018$ |
| $s_2 = 6.89 - 0.103h$ | 0.25 | 0.13 | 0.026 |
| $s_2 - s_6 = +0.09 + 0.057h$ | 0.21 | 0.11 | 0.022 |
| $s_2 - s_{10} = -0.30 + 0.099h$ | 0.21 | 0.11 | 0.022 |

This shows that the amount of aqueous vapor in the air decreases at the rate of 0.146 gram per cubic meter for each increase of 100 meters in the elevation. The course of the daily period is peculiar. Between 6 a. m. and 2 p. m. the vapor tension increases about 0.1 millimeter in the lowlands (100 meters), and about 0.07 millimeter in the highlands (1,000 meters). But the equation for $s_2 - s_{10}$ shows that up to elevations of 300 meters the vapor tension continues to increase until 10 p. m., and that in the lowlands this increase is even greater in the late than in the early hours. At 300 meters we have $s_2 = s_{10}$; and only at greater elevations does condensation occur during the afternoon. For the periodic observations the equations were

$$s_6 = 6.80 - 0.160h$$
$$s_2 = 6.89 - 0.103h$$
$$s_{10} = 7.19 - 0.212h$$

It appears, therefore, that, while the least vertical decrease of temperature occurs in the early morning, the least vertical decrease of vapor takes place during the afternoon. The greatest difference in the amount of watery vapor on mountains and over lowlands occurs at 10 p. m. We must endeavor to derive the laws which govern the daily periods of these coefficients of altitude from the records of continuously registering apparatus. These offer important hints for theoretical investigations. For the relative humidity the results were

$$r = 74.5 + 1.02h \text{ per cent}; \quad \mu = \pm 3.3; \quad \mu_a = \pm 1.7; \quad \mu_b = \pm 0.34;$$

and for cloudiness, expressed in tenths

$$w = 6.40 + 0.027h; \quad \mu = \pm 0.26; \quad \mu_a = \pm 0.14; \quad \mu_b = \pm 0.027.$$

These last two elements, therefore, increase with the altitudes; the relative humidity at the rate of about 1 per cent per 100 meters, and the cloudiness 0.03 tenths, or 0.3 per cent.

Finally, with regard to the phenomena of precipitation, the total amount of the annual precipitation $N$ and the portion of it which had fallen as snow $S$, as found from the observations at 15 stations from 1864 to 1890, were (in centimeters)

| | | | |
|---|---|---|---|
| $N = 50.1 + 5.37h$; | $\mu = \pm 5.5$; | $\mu_a = \pm 2.9$; | $\mu_b = \pm 0.58$. |
| $S = 0.1 + 3.31h$; | 3.5; | 1.8; | 0.37. |

The difference between the two equations shows the portion which fell as rain $R$ to have been

$$R = 50.0 + 2.06h \text{ centimeters.}$$

We may see from the mean errors for $N$ and $S$ that the law of proportional increase of precipitation and altitude has more validity for snow than for the total precipitation.

### THE LUSTRUM 1860–'90.

The system of rainfall stations, established during the first years of our decade and including about 160 stations, made it possible to find the lustral means for the period 1886–'90 without any interpolation whatever. The results by months and years were represented according to the formula $a + bh$, and gave the following constants for the annual values:

For the total precipitation $N$ and the portion $S$ of the same

$$N = 56.7 + 4.93h \text{ cm.}; \quad n = 117; \quad \mu = \pm 6.7; \quad \mu_a = \pm 1.2; \quad \mu_b = \pm 0.29.$$
$$S = .3.6 + 2.80h \text{ cm.}; \quad 111; \quad 3.1; \quad 0.6; \quad 0.14.$$

$n$ denotes here the number of stations from whose data the equations were deduced.

The coincidence in the coefficients of altitude as obtained, first from 15, and then from 117 and 111, annual values, representing respectively the means of twenty-seven and five years, is worthy of remark. It shows that the principle of direct proportion between precipitation and altitude is well founded, and that a small number of stations, if favorably situated, is sufficient for the derivation of the coefficients of altitude.

The large number of stations had, of course, only a favorable effect on the derivation of the coefficients, as is proven by the mean errors. For the portion which fell as rain we obtained

$$R = 5.31 + 2.13 \text{ centimeters.}$$

Besides the amount of precipitation the frequency of its occurrence is of great importance, and this is expressed in the simplest way by the number of days of precipitation. There was found:

(*a*) for the number of days with any precipitation at all,

$$171 + 3.6h, \ n = 91, \ \mu = \pm 20, \ \mu_a = \pm 4, \ u_b = \pm 1.0;$$

(*b*) for the number of days with measurable precipitation,

$$149 + 4.3h, \ n = 116, \ \mu = \pm 19, \ \mu_a = \pm 4, \ \mu_b = \pm 0.8;$$

(*c*) for the number of days with more than 1 millimeter precipitation,

$$97 + 5.5h, \ n = 106, \ \mu = 0, \ \mu_a = 0, \ \mu_b = 0.0;$$

(*d*) for the frequency of precipitation in solid form, as number of days with any snowfall at all,

$$34 + 5.4h, \ n = 102, \ \mu = \pm 20, \ \mu_a \pm 4, \ \mu_b = \pm 0.9;$$

(*e*) number of days with measurable snowfall,

$$24 + 4.9h, \ n = 11, \ \mu = \pm 19, \ \mu_a = \pm 4, \ \mu_b = \pm 0.8;$$

(*f*) number of days on which hail or sleet fell,

$$2+1.5h,\ n=92,\ \mu=\pm 0,\ \mu_a=0,\ \mu_b=0.0.$$

From this we can deduce the number of days with any rainfall at all (*g*) and the number with measurable rainfall (*h*)

(*g*) $137-1.8h.$

(*h*) $125-0.6h.$

Further there was found for the number of days with dew (*i*), rime (*k*), fog (*l*), and hoar frost (*m*)

| | | | | | |
|---|---|---|---|---|---|
| (*i*) | $104-3.4h$, | $n=70$, | $\mu=\pm 30$, | $\mu_a=\pm 7$, | $\mu_b=\pm 1.7$ |
| (*k*) | $36-0.7h$ | 75 | 19 | 4 | 1.0 |
| (*l*) | $49+6.3h$ | 86 | 43 | 10 | 2.1 |
| (*m*) | $1+3.4h$ | 84 | 0 | 0 | 0.0 |

Of importance also is the number of days with night frost (*n*), for which we found

$$93+11.9h,\ n=82,\ \mu=11,\ \mu_a=3,\ \mu_b=0.6$$

There remains to be considered the number of days with snow on the ground. For these we obtained

$$43+7.7h,\ n=73,\ \mu=\pm 12,\ \mu_a=\pm 3,\ \mu_b=\pm 0.7.$$

Concerning this element I believe myself justified in asserting, contrary to the views held by my honored colleague, Wojeikof, that I was the first one to introduce a method of systematic information relative to the depth, limits, etc., of the snow on the ground. This is sufficiently evidenced in my *Jahrbüchern*.

Formerly I caused to be noted only degrees of depth of snow, by indices; but direct measurements were introduced several years ago, without, however, making much use of these data. Not until last year were the data computed as received, and the following equations found:

*Depth of snow on ground*, 1892–'93 (*centimeters*).

| | | | | | |
|---|---|---|---|---|---|
| Feb. 1892, 1st decade | $-11+5.1h$, | $n=160$, | $\mu=\pm 4$, | $\mu_a=\pm 0.7$, | $\mu_b=\pm 0.16$ |
| Feb. 1892, 2d decade | $-20+8.9h$ | 160 | 13 | 2.1 | 0.50 |
| Feb. 1892, 3d decade | $-18+6.5h$ | 160 | 13 | 2.1 | 0.49 |
| Mar. 1892, 1st decade | $-17+6.5h$ | 151 | 14 | 2.2 | 0.52 |
| Mar. 1892, 2d decade | $-13+8.4h$ | 151 | 15 | 2.4 | 0.57 |
| Mar. 1892, 3d decade | $-14+5.2h$ | 151 | 11 | 1.8 | 0.42 |
| Dec. 1892, | $-8+8.3h$ | 115 | 4 | 0.7 | 0.17 |
| Jan. 1893, | $+8+6.5h$ | 106 | 10 | 1.9 | 0.44 |

On looking over these figures surprise will be felt that an element, which at first sight appears to be so very much influenced by local conditions, drifts, etc., admits of being represented with such a degree of certainty. It would be of interest, by all means, to compare the equations for depth of snow with those which express the amount of measurable snowfall and the duration of snow on ground. This calculation for the years 1892 and 1893 has, unfortunately, not yet been commenced. We are therefore compelled to use the equations obtained from the lustrum 1886 to 1890.

I will put these side by side:

| | Depth of snow on ground. | Amount of measurable snowfall. | Duration of snow on ground. |
|---|---|---|---|
| February | $-16 + 6.8h$ (cm.) | $+1.2 + 0.55h$ (cm.) | $18 + 1.5h$ days. |
| March | $-15 + 6.7h$ | $+1.3 + 0.57h$ | $10 + 2.3h$ |
| December | $-3 + 3.3h$ | $+1.8 + 0.31h$ | $9 + 1.9h$ |
| January | $+3 + 6.5h$ | $+0.2 + 0.44h$ | $12 + 2.1h$ |

The parallelism of the coefficients of altitude for amount and duration is noteworthy in the above equations. Especially striking is the fact that the coefficients of altitude for depth of snow are about twelve times larger than those for amount of snowfall. How far this is due to chance may remain an open question. But it is interesting, at all events, to see here approximately the ratio of depth of snow to its yield in water.

In conclusion, I will present the results of the observations made in 1892 concerning the dates of blooming and harvesting of the most important field crops. For the time of blooming the following fundamental equations were obtained:

| | $a$ | $b$ | $n$ | $\mu$ | $\mu_a$ | $\mu_b$ |
|---|---|---|---|---|---|---|
| Rye | May 24 | $+ 4.05h$, | 59, | $\pm$ 5.4, | $\pm$ 1.6, | $\pm$ 0.39 days |
| Wheat | June 17 | $+ 2.83h$, | 28, | $\pm$ 4.4, | $\pm$ 2.1, | $\pm$ 0.67 days |
| Oats | June 28 | $+ 3.41h$, | 41, | $\pm$ 6.5, | $\pm$ 2.3, | $\pm$ 0.57 days |
| Barley | June 17 | $+ 4.76h$, | 12, | $\pm$ 7.4, | $\pm$ 5.8, | $\pm$ 1.80 days |
| Potatoes | July 3 | $+ 1.82h$, | 23, | $\pm$ 6.8, | $\pm$ 3.0, | $\pm$ 0.76 days |

It appears, therefore, that the time of blooming of the three principal cereals is retarded from three to four days for each increase of 100 meters in the elevation. The coefficients of altitude for barley and potatoes are as yet so uncertain that, possibly, in the course of time the same results will be obtained for them as for the three principal grains.

For the length of time between blooming and harvest we obtained:

| | $a$ | $b$ | $n$ | $\mu$ | $\mu_a$ | $\mu_b$ |
|---|---|---|---|---|---|---|
| Rye | 44 | $+ 2.55h$, | 56, | $\pm$ 7.3, | $\pm$ 2.2, | $\pm$ 0.53 days |
| Wheat | 41 | $+ 1.97h$, | 27, | $\pm$ 5.1, | $\pm$ 2.5, | $\pm$ 0.78 days |
| Oats | 27 | $+ 3.22h$, | 38, | $\pm$ 7.9, | $\pm$ 2.7, | $\pm$ 0.63 days |
| Barley | 42 | $+ 0.07h$. | 9, | $\pm$ 5.2, | $\pm$ 4.8, | $\pm$ 1.45 days |
| Potatoes | 75 | $+ 0.94h$, | 16, | $\pm$ 10.5, | $\pm$ 7.7, | $\pm$ 2.05 days |

If we combine the equations for time of blooming and for the difference between time of blooming and harvest, we obtain the equations for the date of harvesting:

| | |
|---|---|
| Date of rye harvesting | July 6 $+ 6.6h$ |
| Date of wheat harvesting | July 28 $+ 4.8h$ |
| Date of oats harvesting | July 25 $+ 6.6h$ |
| Date of barley harvesting | July 29 $+ 4.8h$ |
| Date of potato harvesting | Sept. 16 $+ 2.8h$ |

## 2.—THE INFLUENCE OF MOISTURE, TEMPERATURE, AND LIGHT CONDITIONS ON THE PROCESS OF GERMINATION.

Dr. W. Detmer.

The question concerning the influence exerted by external conditions on the process of germination claims a high degree of scientific, as well as practical, interest. In conducting purely theoretical investigations special preference has been given to the study of this process, in order to reach a more comprehensive understanding of the relations existing between many phases of plant life, on the one hand, and the influence of external circumstances, on the other. Indeed, investigation of this sort has materially advanced our knowledge of the exceedingly complicated processes of plant metabolism, growth, the phenomena connected with the sensitiveness of plants to external conditions, etc. The practical importance of such investigations is clear. Agriculture, as well as forestry and horticulture, have already derived many benefits from utilizing the results of the studies of the process of germination.

It is certainly no superfluous undertaking to present the subject indicated by the title of this paper from the standpoint of our present knowledge; and I take the more pleasure in doing so from the fact that I have been personally engaged for years in experimental work relative to germination, the results of which have been published in various treatises and books.[1]

The term germination is used in this paper to designate, primarily, that particular process which takes place during the evolution of the embryo of seeds. But it is unavoidable, and appears even necessary also, to refer occasionally to the germination of bulbs and tubers and, in general, to all such processes in the course of which, as in the germination of seeds, the organs of plants reach their development at the expense of nutritive matter held in reserve; for the physiologic processes in all such cases are very similar, and the influence exerted on them by moisture, heat, and light conditions shows many analogies.

In the preparation of this paper full consideration has been given to the very extensive modern literature on the subject, and specially important works have been accurately cited.

### THE FUNCTION OF WATER IN GERMINATION AND THE TURGESCENCE OF SEEDS.

The specific course of development of seedlings depends upon internal, hereditary, or historic conditions, which are inherent in the

[1] Detmer, *Vergleichende Physiologie des Keimungsprozesses der Samen*, 1880. *Lehrbuch der Pflanzenphysiologie*, 1883. *Das pflanzenphysiologische Praktikum*, 1888.

nature of the embryo itself, and also upon external influences. As regards the latter, water, presence of oxygen, and temperature conditions are the most important factors. Without the presence of a sufficient quantity of moisture, there can be no germination whatever, a fact proved by daily experience, and which can also be demonstrated on physiologic principles.

Seeds that have reached maturity are for the most part quite destitute of water; they have changed into the so-called air-dried condition. Under favorable conditions many seeds are capable of germinating immediately after maturing; others must pass through a period of rest before development is possible. In a state of maturity many seeds, if kept in a dry place, retain their germinating power for very long periods. It is true that Count Sternberg's statement, that wheat taken from Egyptian mummies was found to be still capable of germinating, has proved to be incorrect; but it is known that common kidney beans, thirty-seven years old, and grains of rye, one hundred and forty years old, can, in some cases, still be made to germinate; and in 1834, in the Dordogne, a number of stone coffins were dug out of Roman graves, dating back to the third and fourth centuries, A. D., which contained large quantities of various species of plants, many of which, for instance, *Medicaga lupulina*, *Centaurca Cyanus*, were found to still retain their germinating power. On the other hand, there are kinds of seed which absolutely can not endure remaining in an air-dried state. The embryo of willow seed, for instance, loses its germinating power when the seed remains in a dry condition for only ten or twelve days.

The above-mentioned fact, that without imbibition of water there can be no germination of seeds, is readily explained on physiologic principles. The growth of the embryo is strictly dependent upon the numerous processes involving change of matter, in the course of which the reserve matter stored up in the endosperm, perisperm, or in the cotyledons is made to provide such materials and forces as are necessary for the development of the young plant; and to bring about these changes water is an absolute necessity. According to my investigations, for instance, air-dried seeds in a state of rest do not respire.[1] They neither absorb oxygen from their surroundings, nor do they give out carbonic acid. In the absence of sufficient quantities of water the live molecules of albumen, upon whose dissociation, in my opinion, ultimately depend all vital processes,[2] are, so to say, in a torpid state. Only the access of water rouses them to activity. I found also that 60 pea seedlings nine days old produced in one hour and forty

[1] Detmer, *Sitzungsber. d. Jenaischen Gesellsch. für Medicin u. Naturw.*. 1881.

[2] *See* my works cited in the introduction, and Detmer in *Pringheim's Jahrbüchern für wissensh. Botanik*, vol. 12.

minutes, and at a temperature of 20.8° C., 0.028 gram $CO_2$. The same specimens, after drying for five days, produced only 0.0095 gram $CO_2$ in the same time and under almost exactly the same conditions. A supply of water again increased the respiration of the plants to a marked degree.

Water is necessary if, during the germination of starchy seeds, the starch is to be converted into dextrin and maltose or glucose by means of diastatic fermentation; or, if there is to be a transformation of fats or reserve cellulose into substances suitable for the regeneration of the living molecules of albumen. Only the presence of water makes possible the translocation of the plastic material in the germinating seed—the transference of mineral matter, nitrogenous or non-nitrogenous bodies—from the cotyledons or endosperm to the embryo. In addition, every process of growth, including, therefore, that of the cells of the embryo, depends upon a bountiful supply of water. Growth can take place only when the membranes and protoplasm are saturated with water; that is, when the cells are in an advanced state of turgescence. H. de Vries[1] found as a fact that a decrease in the amount of water contained in cells lessened the rapidity of their growth.

As for the beginning and progress of the germination of seeds, so is water necessary for the germination of spores or pollen grains, and for the budding or sprouting of twigs, tubers, bulbs, rhizomes, etc. But many of these organs—potato tubers, for instance—do not dry up after reaching maturity, but continue in a watery condition during winter. A corky tissue on their surface protects them against any material loss of water, so that when the tubers begin to germinate the shooting sprouts command an abundant supply of moisture.

After having demonstrated in the foregoing the great significance of water to the process of germination, it also concerns us to investigate the manner in which seeds take up water during their turgescence. In this respect the most important factors are imbibition and the osmotic processes, which will be more fully considered further on. For the present I wish to take into consideration some peculiar modes of absorption of moisture on the part of turgescent seeds.

The seeds of *Canna*, owing to the specific nature of the texture of their testa, are very slow in taking up water. But the swelling process of these seeds would be still more difficult were it not for the presence of special contrivances which, to some extent at least, facilitate the absorption of water, and which consist of numerous fissures in the shell of the seed. These pores suck up the water by capillary attraction, and the fluid is then conducted to the interior parts of the

[1] H. de Vries, *Untersuchungen über Zellstreckung*, p. 56.

testa by means of the intercellular spaces connecting with the stomata.[1]

There are many seeds which, with considerable increase of weight, eagerly take up the water they come in contact with. The cause of this phenomenon (observed, for instance, in the turgescence of the seeds of *Linum usitatissimum*, *Cydonia vulgaris*, and *Salvia pratensis*) is to be looked for in certain peculiar structural conditions of the testa. The microscopic examination of delicate cuttings of flaxseed shows, among other things, that the epidermal cells of the testa, stretched somewhat radially to the surface of the seed, have walls of exceeding density. Chemically considered, the substance of these condensed layers is a gum which, on coming in contact with water, swells with great rapidity and, emerging outward, envelops the whole seed. In this case the taking up of water by seeds is brought about, primarily, by the so-called unlimited turgescence of the gum in the epidermal cells.

Most physiologic processes can only be fully understood by giving the closest attention to the anatomical structure of those organs by which the processes are performed. This very significant proposition, which has been substantiated by frequent experience, has been much better appreciated of late in the critical examination of the phenomena of turgescence; and it is particularly the merit of the Italian investigator Mattirolo[2] to have closely followed this theory. After it had been pointed out by Haberlandt and Nobbe that different portions of the surface of papilionaceous seeds did not suck up water with equal facility, Mattirolo very carefuly investigated the subject from an anatomic as well as a physiologic standpoint.

In the examination of papilionaceous seeds the hilar apparatus is of special interest. It consists of three parts—the double tubercles (glands which secrete large quantities of tannin, as a protection against animal depredations), the hilum, and the micropyle. The last named is capable of opening and closing, according as the neighboring cells are in the act of swelling or drying up. The micropyle readily admits water into the seed; and through it water is also conveyed to the radicle. During normal germination in wet soil, where the position of the micropyle keeps it from direct contact with the wet earth, papilionaceous seeds absorb the water principally through the surface of the testa, and it is the business of the micropyle to convey to the embryo the necessary air, whose oxygen is indispensable to its development.

The very general absorption of water through the seed coats, as well as the diffusion of the water which has already entered into the

[1] Haberlandt, *Schutzeinrichtungen der Keimpflanze*. 1877, p. 10.

[2] Mattirolo and Buscalioni, *Bot. Jahresber.*, 1889, p. 687, and Wollny's *Forschungen*, vol. 15, p. 106.

seed to a certain depth, is brought about by asmotic and imbibition processes, the great importance of which has already been referred to.[1]

All vegetable structures, as cellular coats, starch grains, and the protoplasm, are capable of imbibition. Concurring in Naegeli's ingenious hypothesis, I conceive these structures as built up by an aggregate of molecules which, in the air-dried state of their component parts, are almost in contact with each other. They absorb water when brought in contact with it; the fluid, however, enters into no preexisting cavities, but lodges between the molecules, forcing them apart; and each molecule is surrounded with an envelope of water which is held in place by the force of adhesion. This process is called *imbibition;* and by means of it the substances pass into the *turgid* state. Every turgescent substance is necessarily increased in volume, owing to the absorption of water; but in limited turgescence, which is here under consideration, this increase of volume is slight, and when it has reached its limit, the maximum turgescence has been attained. The capacity of turgescence is, on the other hand, expressed by a number, which indicates how great a quantity of water a body can hold at its maximum.[2]

In the turgescence of seeds, built up from the most multifarious substances, imbibition processes, above all others, play an exceedingly important role. This requires no further demonstration. But when imbibition has once begun, osmotic processes take place also, hastening the absorption of water by seeds. The water penetrates into the interior of the cells, so that some of them eventually begin to swell. It is also from swelling seeds that certain substances pass into the surrounding fluid, organic bodies as well as mineral matter—the latter, probably, for the most part in chemical combination with the former. This well established yielding up of substance on the part of swelling seeds has by no means been fully investigated, especially with regard to the theory established by Pfeffer,[3] concerning the osmotic processes in the living plant.

When seeds are brought in contact with the solution of a salt, instead of with pure water, the fluid does not enter into them in the original concentration. Likewise, imbibition, as well as osmotic processes, frequently tends, in connection with the chemical action of the contents of the cells, to produce a decomposition of the salts (gypsum and chlorides, for instance) as they enter into the swelling seed. Sulphuric acid and chlorine, especially, are not taken up by seeds in

[1] That seeds absorb water, not only by means of the hilar apparatus, but also through the surface of the testa, has been demonstrated by myself and others. See Detmer, *Vergl. Physiol. des Keimungsprozesses*, 1880, p. 66.

[2] For further details see Reinke, *Untersuchungen über Quellung*, 1879

[3] Pfeffer, *Osmotische Untersuchungen*, 1877.

quantities corresponding to the bases to which they were bound.[1] I have also shown that the turgescent capacity of seeds varies inversely as the concentration of the saline solution with which the seeds come in contact, a phenomenon readily to be explained on physical grounds. No less conceivable, from a physical point of view, are the facts established by myself and others concerning the progress of turgescence at different temperatures of the water. Increased temperature materially hastens the progression of both imbibition and osmose, and it is for this reason that turgescence is observed to take place much quicker in warm than in cold water. But the capacity of turgescence and the maximum turgescence are eventually the same in each case, *i. e.*, the same increase of weight and volume takes place in the seeds whether turgescence is proceeding in warm or cold water, only the time varies in which turgescence is accomplished.

In the course of the processes which produce turgescence in seeds, internal as well as external work is performed. Heat is liberated also, especially in the beginning of turgescence, so that the conversions of energy involved become very complicated. A mathematical treatment of the subject would carry us too far in this paper. I will only cite a few facts to justify my assertions. I have mixed potato starch and pea meal of accurately known temperature with water of the same temperature. A striking increase of temperature followed at once. If potato flour is dried and, after cooling, brought in contact with water, the temperature will rise at once more than 6° C. In every imbibition process, therefore, as well as during the turgescence of seeds, there is a condensation of the water which has penetrated between the molecules of organisms, and this must produce a liberation of heat. If the substance has by drying been entirely, or almost entirely, freed from water, the liberation of heat will be specially marked. The increase of temperature noticed *after* turgescence, in the course of the germination of seeds, is due no longer to imbibition, but chiefly to entirely different causes. It is due to the transmutation of matter (dissociation of the living molecules of albumen and respiration), which process is very generally accompanied with development of heat.

That internal work is being performed during the turgescence of seeds is at once evident from the fact that they materially increase in volume in consequence of the absorption of water. External obstacles to turgescence can be overcome, if they are not altogether too serious. One of my pupils. with the aid of an apparatus constructed by myself, has recently made special experiments relative to the measurement of the external work performed by swelling seeds. The apparatus consists mainly of a cylinder containing the swelling seeds, upon which latter rests a small plate of metal to whose upper

[1] Knop, *Kreis auf des Stoffs.* vol 2, p. 200.

face is fastened a metallic rod, moving within a guide. This rod carries on its upper end a second plate of metal, which serves to hold the weights. With this apparatus we found, for instance, that 10 grams of swelling peas could raise a weight of 1,000 grams—a performance of considerable magnitude.

It is of interest to determine closely the capacity of turgescence, *i. e.*, the amount of water absorbed by seeds during the swelling process. An entirely accurate measurement of this amount is not obtained so easily, as the increase in the weight of swelling seeds does not express with absolute correctness the amount of water absorbed by them. It must be remembered that seeds permit the escape of small quantities of organic bodies and mineral matter into the water surrounding them; that they produce carbonic acid; and in many cases (as with oily seeds) absorb a relatively large amount of oxygen, without exhaling a corresponding amount of carbonic acid. But, in general, it may be said that the difference in weight between dry seeds (in a state of rest) and swollen seeds furnishes a fairly reliable means for determining their turgescent capacity. In this respect the following statements by Nobbe[1] are especially worthy of attention:

*Absorption of water by dry seeds or fruits.*

| | Per cent. | | Per cent. |
|---|---|---|---|
| Wheat | 60.0 | Broad (or hog) beans | 157.0 |
| Indian corn | 39.8 | Red clover | 105.3 |
| Peas | 96.0 | Rape | 48.3 |
| Kidney beans | 100.7 | Oil radish | 59.5 |

At the beginning of the "evolution of the embryo," when the radicle and hypocotyl are extending themselves, and the cotyledons are developing, there is still a considerable increase in the amount of water contained in the seedling, mainly because many newly formed cells, producing energetic osmotic processes, are then in a state of active turgescence.

The above examples and many other observations show, above all, how considerable are the quantities of water absorbed by papilionaceous seeds during the swelling process. Graminaceous and oily seeds, on the other hand, have a smaller turgescent capacity. Special experiments made by myself demonstrated, however, that different specimens of a given kind of seed by no means absorb the same quantity of fluid, though, to be sure, the variation is confined within small limits. Thus, it will be seen that at this stage the specific behavior of the individual specimen finds expression. I have also published in my *Keimungsphysiologie* the results of experiments concerning the time rate of the swelling process. Experimenting with peas, I found that they absorbed water slowly during the first stages of swelling, more rapidly later on, and slower again during the last stages.

[1] *Handbuch der Samenkunde*, p. 119.

As has already been pointed out, every turgescent process is naturally combined with an increase of volume on the part of the turgescent substance. This fact is readily demonstrated by bringing grains of starch, wood, or seeds in contact with water. Papilionaceous seeds, in particular, show a marked increase of volume. Peas, for instance, occupy twice as much space after they have absorbed water as before. Somewhat complicated become the phenomena which appear in investigating the question whether the aggregate volume of the seeds and the water with which they are in contact is itself increased or decreased during turgescence. Nobbe, Mattirolo,[1] and myself[2] have closely investigated this subject, using papilionaceous seeds in particular. I covered some white giant beans in a cylinder with water, completely filling the apparatus, which was then closed with a rubber stopper having two holes pierced through it. One hole served to admit a thermometer, the other for the insertion of a straight glass tube. In the beginning of the experiment the fluid rose in the tube, showing that during the first stage of turgescence there was an increase of the aggregate volume. After about three-quarters of an hour the water in the tube reached its highest point, and then fell during several hours (decrease of aggregate volume during the second stage), after which it again rose quickly during the third stage.

The increase in the volume of the seeds alone, and the variations in the joint volume of seeds and fluids, as observed during the swelling process, must, therefore, be kept distinctly apart. As regards the latter there are also various points concerning the causes of the phenomena observed, which are by no means entirely clear. Mattirolo has recently adopted my own view, that there is an increase in the volume of both seeds and water during the first stage of swelling, in which at first only the coat of the seed absorbs any considerable amount of water. The coat becomes wrinkled and detaches itself from the cotyledons, creating spaces filled with rarefied air. I have reached this view mainly from certain experiments in which I used peas with damaged testas. Mattirolo experimented in a somewhat different manner, but reached the same conclusion as I did. If, now, in the course of the swelling process of the testa cells, or by means of the micropyles, water penetrates into the space between the testa and the cotyledon, there must result a decrease in the joint volume of seeds and water. The causes of the renewed increase in the joint volume, which occurs later on during the third stage of turgescence, are not yet fully understood; but I believe I have clearly shown that this increase is due mainly to the anatomic structure of the pea seeds.

If a certain number of seeds of different vegetable species are cov-

[1] Mattirolo, *Archiv ital. de biologie*, vol. 15, 1891, fasc. I.

[2] Detmer, *Keimungsphysiologie*, p. 72.

ered with water, continued observation will show that some or many individual seeds remain hard and unswollen after having been kept in the water for weeks or months. This difficult turgescence, which has been closely examined into by Nobbe, Höhnel, and myself, pertains to seeds of the most diversified families of plants, as for instance, *Lupinus*, *Trifolium*, *Robinia* (in general to almost all papilionaceæ), *Chenopodium album*, *Polygonum persicaria*, *Rumex crispus*, *Veronica hederaefolia*, *Cuscuta*, etc. With *Robinia*, as well as in other cases, this difficult swelling is carried so far that many individual seeds can remain in water for years without getting soft. The cause of this remarkable phenomena must be looked for in the specific nature of the outermost layers of the seed coats. In papilionaceous seeds the palisade layer of the testa, if entirely intact, presents a great obstacle to the entrance of water; and it is only very gradually, and in consequence of a change of substance, that this layer becomes pervious to water. If the testa is injured, the water enters the seed at once and causes it to swell.

In a biologic sense, slow turgescence is of great importance to the continued existence of vegetable species, so that its wide extension is not to be wondered at. If all seeds maturing during summer or fall could forthwith swell and germinate with ease, then the continuance of many species of plants would be most seriously endangered, as the plantlets would perish from the cold of winter. But if, as is actually the case, many seeds can lie in the ground through the winter without swelling, and swell and germinate during the spring or summer only, the species must be preserved, though countless seeds may have already perished.

In this connection brief reference must also be made to the influence exerted by the drying up of seeds or seedlings, which frequently takes place in nature. Some species of seeds, as those of the willow and *Oxalis* families, for instance, can not endure drying up after reaching maturity. Most seeds are very hardy in this respect, and survive even artificial drying at a temperature of 30° or 40° C. without material injury. Seeds already turgescent and then dried again generally escape serious damage to their vitality, while, on the other hand, drying up may be fatal to seedlings, and the more so the further their development has advanced.[1] It is a remarkable, and and as yet by no means a physiologically explained, fact that the partial drying of potato tubers in many cases materially increases the productivity of the plants grown from them.[2]

Finally, it should not remain unmentioned that some of the organs

[1] For further particulars see Schroeder, *Untersuchungen aus dem botanischen Institute zu Tübingen*, edited by Pfeffer, vol. 2, p. 7.

[2] For further particulars see Wollny, *Saat und Pflege der landwirtschaftl. Kulturplanzen*, 1885, p. 307.

of germinating seeds undergo certain peculiar movements because of differences in the amount of moisture contained in their surroundings. If in the vicinity of a radicle there is a dry body on one side and a moist one on the other, it will turn and curve toward the latter. Roots are positively hydrotropical;[1] and biologically, this property is of course very useful to them. The hydrotropism of the plumule is developed only feebly or not at all.

## THE INFLUENCE OF TEMPERATURE ON THE PROCESS OF GERMINATION.

Daily experience teaches how important is the influence of temperature conditions on plant life. Indeed, the vital processes take place only within certain limits of temperature, and come to a standstill if the plants are exposed to either too high or too low a temperature.

The temperature of the plants themselves depends mainly, but not entirely, on the temperature of their surroundings. Transpiration, for instance, which is quite abundant in some plantlets, causes a decrease in the temperature of the plant, because, in the production of hydrogen, heat is expended, which can, in part, be drawn from the plant. More important to us is the fact that metabolism and respiration result in the liberation of latent heat; and for this reason germinating seeds, protected from evaporation, are generally observed to acquire a higher temperature than that of their surroundings. Wiesner[2] and Eriksson[3] carefully studied these particular phenomena, and found that the heat produced by germinating seeds was in many cases sufficient to raise their temperature from 1° to 2° C. above that of their surroundings. But this takes place only if the plantlets, in the presence of oxygen, maintain a normal respiration, while with intermolecular respiration of germinating seeds Eriksson could demonstrate, at most, a rise in temperature of 0.2° C.

In this section it will be our main object to consider the influence upon germinating seeds of such temperature conditions as admit of their development. But first of all we must refer to the injuries to which seeds, buds, etc., are exposed under the influence of very low or relatively high temperatures.

A very high degree of interest attaches to the fact, which is also biologically important, that such parts of plants as are poor in water withstand low temperatures very generally without material damage. I have often convinced myself that air-dried seeds, which had been exposed for a considerable length of time to temperatures of from —5° to —10° C., would subsequently germinate under normal conditions, while the same low temperatures destroyed the life of turgescent seeds. My experiments were made with seeds of *Pisum* and *Triticum*. In

[1] Sachs, *Arbeiten des botan. Instituts in Würzburg*, vol. 1, p. 209.

[2] Wiesner, *Versuchstationen*, vol. 15.

[3] Eriksson, *Pfeffer's Arbeiten aus d. botan. Instit. zu Tübingen*, vol. 1.

experimenting with oil seeds several investigators have shown that, even when partly swelled, their vitality is but slightly affected by temperature conditions;[1] a fact which can only be understood by taking into consideration their relatively small turgescent capacity as compared with others. The capacity of air-dried seeds to resist low temperatures is so great that, according to C. de Candolle,[2] they can readily endure a temperature of —60° C. for a considerable length of time. The same holds good for dry spores of fungi, and we can see by the buds of our trees and shrubs how easily they are destroyed in the sappy state by the frosts of spring, while sapless they endure the lowest winter temperatures.

The sensitiveness of the sappy parts of plants to low temperatures varies exceedingly. The above-ground organs of *Dahlia variabilis* and of many species of *Cucurbita* and *Phaseolus* are killed by light frosts, while leaves and stems of *Bellis perennis*, *Stellaria media*, etc., perish only with lower temperatures. The succulent leaves of *Viscum album* are probably not damaged by the lowest temperatures experienced in our latitudes. Many plants, among them several mosses, can remain for a long time in a hard-frozen condition without showing any material damage after thawing, whether the latter process takes place slowly or very suddenly. On the other hand, the theory prevailed until recently, and was advocated by Sachs[3] in particular, that when an organ perished from cold it was not in direct consequence of the freezing of its juices, but owing to the manner of thawing. It was held that frozen turnips, potatoes, cabbage leaves, etc., could be saved by thawing them very gradually, while, on the other hand, rapid thawing would destroy them. After numerous experiments I, as well as other observers, have come to the conclusion that the view held by Sachs is not tenable.[4] According to my experience the effect of freezing itself is directly fatal to such objects as were used in Sachs's experiments. This can be demonstrated beyond a doubt with the leaves of *Begonia manicata;* for the death of their tissues involves a change in the color of the leaves, and according to my observations this change always takes place when the leaf is made to freeze.

The formation of ice in freezing plants does not take place at 0° C., but only at lower temperatures, sometimes not until —4° C. Müller-Thurgau,[5] who has closely investigated the phenomena attending the freezing of plants, has demonstrated that the reason why the formation of ice in the cells can begin only at temperatures below 0° C. is to be found in the fact that the sap of plants does not repre-

[1] Tautphön, *Dissertation, München*, 1876.

[2] C. de Candolle, *Bot. Zeitg.*, 1880, p. 64.

[3] Sachs, *Verhandl. d. Gesellsch. d. Wiss. zu Leipzig*, 1860, vol. 12, p. 27.

[4] Detmer, *Bot. Zeitg.*, 1886, p. 30; *und Pflanzenphys. Praktikum*, p. 78.

[5] Müller-Thurgau, *Landwirtschaftl. Jahrb.*, vols. 9 and 11.

sent pure water, and that it is also partly bound by imbibition on the part of the vegetable structures. Experiments made by Clausen,[1] under my direction, have proved that germinating lupines, for instance, freeze at about —4° C.

The water does not freeze in the interior of the cells; and the increase of volume which accompanies the formation of ice, and which would otherwise tear the cellular walls, can not, therefore, produce the destruction of plants, except in very rare cases, when the freezing takes place with great rapidity. In freezing, the water passes from the cells into the intercellular spaces where it solidifies. The lower the temperature falls, the more ice is formed; a fact which is important in considering the otherwise inexplicable phenomenon that many plants can stand freezing at —8° C., but perish on being exposed to a temperature of —20° C.

Congealed parts of plants assume a hard, glassy, brittle condition; if killed and thawed they are soft, limp, and often discolored, and on slight pressure exude considerable quantities of fluid.

All these phenomena are readily understood if we adopt the well-founded theory that the effect of frost, when it kills, is to disorganize and destroy the protoplasm of the cells. In consequence of this the cellular fluid leaves the plasma; at the same time the nature of the hyaloplasmic layers undergoes a complete change, and they are now pervious to many substances which, in a normal condition, they did not permit to pass. This is the cause of the discoloration of frozen plants, and of the phenomenon that pieces of frozen red beet, if put into water, readily part with coloring matter and sugar, while the living cells tenaciously retain these substances.

For reasons already alluded to, it is especially in the spring that open air vegetation is exposed to the danger of being killed by frost. As a protection against excessive cooling by radiation, young plants may be covered with brush, or smoking fires may be kindled, an expedient practiced in Peru before the discovery of that country.

Young plants are very much exposed to the danger of perishing from cold in the spring, when the upper strata of the soil alternately thaw and freeze again. This causes an uplifting of the soil and of the plantlets. In thawing, the soil falls back, but the young plants do not follow correspondingly, so that after several repetitions of this process they are left on the surface, some with the end of their roots torn off, if the lower unthawed layers of the soil held them fast. Drainage and sowing early enough to insure strong roots even before winter sets in are good preventives in this case.

In considering the effect of relatively high temperatures on plants, we again meet with the specifically different behavior of the organ-

[1] Clausen, *Landwirtschaftl. Jahrb.*, vol. 20.

isms. Very many sappy plants and sprouting seeds will perish if immersed from ten to forty minutes in water at from 47° to 48° C. In heated air they will endure a slightly higher temperature.[1] Some algæ (*Oscillaria*), on the other hand, are not materially affected by such temperatures, for it has been demonstrated beyond a doubt that they thrive in water at a temperature of from 50° to 52° C. There are bacteria spores, but only a few kinds, which can remain from one to two hours in boiling water without losing their vitality.

In a dry state plants are equally as able to resist relatively high as relatively low temperatures.[2] Air dried seeds can easily endure a temperature of from 50° to 60° C. for a considerable length of time; and artificially dried they are able to bear for some time a temperature of 100° C. without total loss of germinating power. Fungi spores are very similar to seeds in this respect.

The cause of the injurious effect of high temperatures is to be found in the destruction of the molecular structure of the protoplasm. The effect is almost the same as that of cold. The killed plants lose their turgidity, and become limp, soft, and discolored, primarily because the chlorophyll pigment is decomposed by organic acids originating with the cellular fluids and forcing themselves into the chlorophyll granules.

If we now take up the question of the effect upon plants (especially upon seeds and young plants) of such temperatures as are absolutely necessary to the vital processes of vegetation, we must in the first place consider the important fact that for every process there is a minimum, an optimum, and a maximum temperature. Minimum is applied to the lowest temperature at which a process begins to manifest itself. With rising temperature the process is accelerated, until at the optimum temperature it manifests the greatest energy. A further rise in temperature lowers the energy, and when the maximum temperature is exceeded the physiological processes cease entirely.

The position of the three cardinal points, the minimum, optimum, and maximum, is by no means the same for the various physiological processes which take place in a plant or an organ; it also varies for a given process in different species of plants, and is even influenced by the degree of development of an organ. In order to give a general idea as to the position of the cardinal points in the germination of some seeds and the growth of the plantlets, I append the following figures which were determined by Sachs,[3] Köppen,[4] and de Vries:[5]

[1] See especially H. de Vries, *Archiv Néerlandaises*, vol. 5.

[2] Detmer, *Vgl. Physiologie d. Keimungsproz. d. Samen*, p. 401.

[3] Sachs, *Lehrb. d. Botanik*, 4th ed. p. 802.

[4] Köppen, *Wärme und Pflanzenwachsthum*, 1870, p. 43.

[5] H. de Vries, *Archiv Néerlandaises*, 1870, vol. 5.

*Germinating temperatures of some seeds.*

| | Minimum. | Optimum. | Maximum. |
|---|---|---|---|
| | ° C. | ° C. | ° C. |
| Triticum vulgare | 5.0 | 28.7 | 42.5 |
| Sinapis alba | 0.0 | 21.0 | 28.0 |
| Trifolium repens | 5.7 | 21.25 | 28.0 |
| Phaseolus multiflorus | 9.5 | 33.7 | 46.2 |
| Pisum sativum | 6.7 | 26.6 | ............ |
| Cucurbita Pepo | 13.7 | 33.7 | 46.2 |

According to later investigations by Uloth[1] and Haberlandt,[2] the position of the minimum for the germination of many seeds, including some of those mentioned in the above table, is often a lower one than was formerly supposed. These observers witnessed the germination of many seeds that had been planted in a box kept in an ice house and surrounded with ice. It is evident that in these instances the growth of the embryonic parts must have taken place at a temperature of about 0° C., as warming by the admission of light was totally prevented in some of the experiments, and the individual heat produced by the change of matter in the objects experimented upon must have been very insignificant. Further, many algæ appear to grow energetically in water of 0° C. temperature; and the *Soldanellas* which break through snow-crusts must be capable of robust development at a relatively very low temperature. According to Naegeli, the minimum temperature for the growth of certain bacteria forms is also about 0° C.

While temperatures but slightly above the minimum do not materially promote the process of growth, they may be of great importance to other processes and, indirectly, to that of growth also. In this respect special reference must be made to a very peculiar property of potato tubers. As is known, after maturing and in a normal condition, they pass through a period of rest before germinating. During this period many metabolic processes take place in their tissues in preparation for the sprouting of the tubers; more especially, by means of diastatic fermentation, a conversion of starch into sugar, of which in the course of time a sufficient quantity is accumulated in the tissues. Now, Müller-Thurgau[3] has shown that potato tubers (and some other vegetables act probably in a similar manner) can be made to germinate soon after maturing, *i. e.*, the period of rest can be dispensed with, if they are subjected to a treatment which induces, above all, an abundant accumulation of sugar. For that purpose it is only necessary to expose the ripe tubers for one or two months to a temperature of from 0° C. to 2° C. Under such condi-

[1] Uloth, *Flora*, 1871, p. 185, *u.* 1875, p. 266.

[2] Haberlandt, *Wissenschaftl. prakt. Unters. auf d. Gebiete d. Pflanzenbaues*, 1875, vol. 1, p. 109.

[3] Müller-Thurgau, *Landwirtsch. Jahrb.*, vol. 2.

tions the sugar produced is not respirable in considerable quantities, as is the case at higher temperatures, but it accumulates abundantly in the cells, and under favorable conditions the tubers will quickly germinate. The accumulation of sugar in the tissues is so considerable that the potatoes become sweet. This sweetness is, therefore, by no means due to freezing, as was formerly supposed. In the interest of domestic economy, it deserves to be mentioned that sweetish potatoes may be rendered fit for use again by allowing them to remain for some time in a warm place. The brisk respiration which takes place under such conditions rapidly destroys the sugar.[1]

The optimum and maximum temperatures for growth are in many cases, but not always, higher the more the minimum is above zero. When the maximum is exceeded, growth ceases; but other processes may still take place in the cells. For instance, *Triticum* plantlets cease to grow at a temperature of 44° C., but they continue to respire and evince a renewal of growth if the temperature is reduced to 25° or 30°. The influence exerted in this case upon the growth of cells by the change in temperature has not yet been sufficiently investigated.[2]

The subjoined table presents some values based upon investigations made by Sachs,[3] and they deserve consideration in estimating the position of the cardinal points of temperature for the growth of maize.[4]

*Growth of root at varying temperatures.*

| | Temp., ° C. | Millimeters. |
|---|---|---|
| In 96 hours | 17·1 | 2·5 |
| In 48 hours | 25·2 | 24·5 |
| Do | 33·2 | 39·0 |
| Do | 34·0 | 55·0 |
| Do | 38·2 | 25·2 |
| Do | 42·5 | 5·9 |

As in growth so there may be noticed in other processes which take place during germination a peculiar dependence upon temperature conditions. It has been shown that in many cases normal respiration takes place at temperatures below zero (—1° to —2°). With rising temperature respiration becomes more brisk, and at about 40° C. the optimum temperature is reached for the plantlets of *Lupinus luteus* and *Triticum vulgare*, while the maximum must be looked for at about 45° C.[5] A further increase causes a destruction of the life

[1] See also some remarks on the sweetening of potatoes in my dissertation, *Pflanzenphysiol. Untersuch. über Fermente, Jena*, 1884.

[2] The whole subject relating to the influence of oscillations of temperature on growth should be further investigated, notwithstanding what has been accomplished by Köppen and Pedersen. *Arb. des bot. Inst. in Würzburg*, vol. 1, p. 563.

[3] Sachs, *Lehrb. d. Botanik*, 4th ed., p. 808.

[4] Similar values for other experimental objects were obtained by Sachs, Köppen, De Vries, and Haberlandt.

[5] Detmer, *Ber. d. deutsch. bot. Gesellsch.*, vol. 8; and Claussen, *Landwirtschaftl. Jahrb.*, vol. 20.

of the cells, which becomes more and more marked as the temperature advances; and I have demonstrated with absolute certainty that totally withered plants are entirely unable to produce carbonic acid by respiratory processes.

Increasing temperature, up to the optimum, also accelerates many metabolic processes. My investigations have demonstrated this as regards the conversion of starch, for instance, see *Keimungsphysiologie*. Fermentative processes take place much more rapidly with high than with low temperatures, and the optimum temperature for diastatic effect is actually as high as 63° C.—a temperature almost generally fatal to the life of plant cells. Etiolated plants, grown in the dark, become green quicker if the temperature is raised. For protoplasmic motions the optimum temperature is between 36° and 40° C., and the maximum a few degrees higher. Above the maximum the plasma passes first into a torpid state, until a temperature of from 46° to 52° C. effects the destruction of its structure.

Wortmann[1] has established the interesting fact that parts of plants whose opposite sides are exposed to different degrees of heat perform flexures, due to movements of growth. Thus, the radicles of *Pisum* and *Zea* are positively thermotropic when the warming of one side does not exceed a certain limit (32° to 38° C.); but at a higher temperature they acquire negatively thermotropic properties, *i. e.*, they curve toward the side where the temperature is lower.

### THE INFLUENCE OF LIGHT ON THE PROCESS OF GERMINATION.

While the presence of oxygen and water, as well as certain temperature conditions, must be considered as indispensable to germination, light is, generally speaking, of secondary importance in that process. In most cases germination proceeds not only in the light, but also in total darkness; and the influence of light on the development of plantlets is effective in a limited sense only. But there are exceptions to this rule.

Borodin[2] found that fern spores germinated only in the light, not in the dark; and the same is the case with the spores of *Polytrichum commune*, the gemmæ of *Marchantia polymorpha*, and the seeds of *Viscum*.[3] According to Stebler[4] many varieties of grass seed (*Poa pratensis*, for instance) germinate very imperfectly in the dark (7 per cent), while light produces a very favorable effect (59 per cent germinated). Nobbe,[5] on the other hand, was unable to establish any material influence of light conditions on the germination of grass

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[1] Wortmann, *Botan. Zeitung*, 1885.

[2] Borodin, *Bull. de l'Acad. de St. Petersburg*, 1868, vol. 13, p. 432.

[3] Pfeffer, *Arb. des bot. Instit. in Würzburg*, vol. 1, p. 80; and Wiesner, *die heliotropischen Erscheinungen*, 1878, vol. 1, p. 42.

[4] Stebler, *Verhandlungen des naturwissenschaftl. Vereins in Zürich*, 1881.

[5] Nobbe, *Versuchstationen*, 1882.

seeds (including *Poa* seeds), and this result comes probably nearest to the real facts in the case. However, the literature on this subject is full of contradictions, and in further investigations it will be necessary to more carefully exclude the known sources of error in following the methods heretofore employed.

In the opinion of some observers light has also a *direct* effect on the respiration of germinating seeds. Pouchon[1] claims to have proved that light accelerates the absorption of oxygen during germination. Turjewicz[2] made experiments in the course of which he exposed germinating seeds whose respiration capacity was to be tested to temperatures only slightly above 0° C., which prevented them from becoming green on the admission of light. Under such conditions the plants produced a little more carbonic acid in the light than in the dark.

Wolkoff and A. Mayer,[3] in their most carefully conducted experiments, failed to prove a decided influence of light on the respiration of young plants. Generally speaking, such an influence does not really seem to exist; and where results to the contrary have been obtained, it is safe to say that they were mostly due to faulty experiments. I know from personal experience how difficult it is to accurately regulate the temperature in experiments on respiration under the influence of light; and yet this point has heretofore been frequently overlooked, although as a rule deserving the utmost attention.

The *indirect* influence of light on the respiration of germinating seeds is very considerable, and may be easily verified. One of my pupils tested some well-developed lupine plantlets, which had been exposed to a good light, as to their respiration capacity. They were found to produce a considerable amount of carbonic acid. But after remaining for a few days in a poorly lighted place their respiration became feeble; again placed in a good light their production of carbonic acid increased materially. These phenomena are quite intelligible if we take into consideration the manner in which light acts upon the metabolic process. In my *Lehrbuch der Pflanzenphysiologie*, and elsewhere, I have emphatically advocated the view that the live molecules of albumen experience, under all conditions, a dissociation into nitrogenous bodies (amido acids and acid amides) and into non-nitrogenous groups of atoms. These latter serve the purposes of respiration; for instance, with normal respiration, and while in the nascent state, they are mainly converted into carbonic acid and water by means of atmospheric oxygen. The nitrogenous products of dissociation remain in the cells, and in the beginning of germination they can usually be wholly changed into albumen by means of the

[1] Pouchon, *Comptus Rendus, Paris*, vol. 41.
[2] Turjewicz, *Wollny's Forschungen auf d. Gebiete der Agricultur-physik*, vol. 14.
[3] Wolkoff u. A. Mayer, *Landwirtschaftliche Jahrb.*, vol. 8.

free non-nitrogenous reserve matter (starch, fat, etc.). But if germination proceeds in the dark the reserve matter is forthwith consumed, and the amido combinations accumulate more and more in the tissues, while there is a lack of sufficient material for the production of albumen. Young plants raised in the dark are consequently rich in amido acids and acid amides, but poor in albumen. According to my view, respiration is a function of the live albumen molecules; and its magnitude depends, therefore, on the quantity of such molecules present.

But totally different from their behavior in the dark is the action of plantlets on the admission of light. While the cells of the organs of plants above ground grown in the dark contain greater or less quantities of etiolin grains, which cause their yellow color, the admission of light (and it is especially the less refrangible yellow or orange rays that are most active in this process) changes the color of the young plants into green.[1] Through the action of light there is formed in the protoplasmic base of the chlorophyll bodies the normal green chlorophyll pigment, which is a color mixture of xanthophyll and cyanophyll.

This process at the same time makes possible the assimilative activity of the young plant. Under the influence of light, sugar and starch are produced in the green cells, with a secretion of oxygen, the amount of solid matter in the plant increases materially, and the conditions for normal growth are supplied.

In the light the nitrogenous products of dissociation, generated by the metabolic processes, can not only be regenerated into albumen in their entirety (by means of the carbon hydrates formed in the assimilative process), but even new albuminous bodies are formed from the products of assimilation, on the one hand, and nitrogenous inorganic bodies (nitric acid, for instance), on the other. The abundance of albumen must quicken the respiration of the young plants, and, as we have already seen, this result is easily verified. I can not enter here into details relative to the process of assimilation. The discussion would carry us too far and require too much space. Stress must be laid, however, on the following points:

If a plant remains constantly in total darkness, the weight of its solid (or dry) substance decreases continuously, because a considerable portion of the organic substances is destroyed by respiration. If, for instance, the weight of a dry seed is ascertained, and afterwards also the weight of the dry substance of the young plant developed from the seed in the dark, the phenomenon in question can be readily observed. I have frequently observed that plants cultivated for some

[1] I have satisfied myself that the plantlets of most conifers do not require light in order to become green. They will do so in total darkness. Only ginkgo plantlets produce chlorophyll exclusively in the light. *Bot. Jahresber.*, 1889, p. 79.

time in this manner contained only 50 per cent of the dry substance of the seeds. In the cultivation of young plants in the light, but in an atmosphere free of carbonic acid, there must naturally also be a great loss of dry substance. Assimilation is here excluded, but respiration takes place and destroys organic matter. The case is entirely different when the plant develops in the open air and under the influence of light. Respiration, indeed, destroys organic material, but the creation of new organic matter, in consequence of assimilation, is so energetic as not only to cover these losses, but supply the plant with much more of dry substance than was contained in the seed from which it was raised.

If we now proceed to determine the influence of light on the growth of the organs of young plants, the first question that arises relates to the manner in which a plant develops if permanently excluded from the light. Many blossoms are not at all changed, not even in their coloring, if developed without light. I cultivated hyacinths in total darkness. The leaves and stems grown from the bulbs, which of course did not come up green, exhibited the characteristic marks of etiolated plants; but the blossoms formed were perfectly normal.[1] As regards the growth of stems in the dark, it is found, as a rule, that they reach an abnormal length under such conditions, but frequently remain much thinner than usual.[2] I found, for instance, that the internodes of a *Tropæolum* plant had a total length of 250 millimeters, while that of a similar plant grown in the light was only 30 millimeters.

The leaves of monocotyledonous plants reach a considerably greater length in the dark than in the light, but develop very small surfaces. The surfaces of the leaves of dicotyledons are entirely different in this respect. In the dark their growth is retarded in all directions, they attain no great size, and no not unfold themselves normally.

In some instances the development of the vegetable organs, in the absence of light, does not follow the usual course characterized briefly in the preceding paragraph. Thus, some parts of the stems, for instance, the hypocotyl of such plants as *Pisum* and *Tropæolum*, whose cotyledons are not raised above the soil during germination, remain very short in the dark as well as in the light; though, be it added, the epicotyls stretch themselves prodigiously in the absence of light. The leaves of *Beta* reach nearly the same dimensions in the dark as in the light.

The effects of etiolation, especially the over-elongation of the internodes and the retarded growth of the leaves, can become of great

[1] Sachs found, however, that the normal development of the blossoms of *Tropæolum majus* is possible only with the aid of the ultraviolet rays. *Arb. des botan. Instituts in Würzburg*, vol. 3, p. 385.

[2] Sachs, *Botan. Zeitung*, 1863, Supplement.

importance to vegetation, as has been pointedly referred to by Godlewski.[1]

When the germination of seeds begins deep in the ground, the great elongation of the stalks makes it possible easily to raise the buds above the surface of the ground, in spite of existing unfavorable conditions. The retarded growth of the leaves in the darkness below ground is useful, because it effects a saving of plastic material. It is only when the leaves have reached the light that they can develop assimilative activity, and must then grow larger.

If plants are cultivated, not in absolute darkness, but in a feeble light, they become only partly etiolated. Such partial etiolation is the cause, for instance, of the lodging of the grain in our fields, a phenomenon not due, as was formerly supposed, to a want of silicic acid. If the grain was very thickly sown, or has grown too thick-stemmed in consequence of heavy manuring, so that the stalks are too close together, little light is received by the latter, especially on their lower parts. They etiolate in part, become long and thin, and do not form normal mechanical tissue, so that the plants lean over, a circumstance which may, of course, prove very detrimental to the farmer.

Etiolation phenomena appear not only when the entire plant remains in darkness, but individual organs will also become etiolated if put into a dark place without being separated from the parent plant, and the latter is kept in the light. I have demonstrated this fact in experimenting with beans in particular.

If suitable objects for experiment (plantlets, for instance) are cultivated, some under the influence of the less refrangible rays of light which have passed through a solution of bichromate of potash, and others under the influence of the more refrangible rays passing through a solution of ammoniac copper, it will be found, according to Sachs[2] and Vines,[3] that etiolation phenomena appear in the former case only, while in the latter the behavior of the plants is the same as in daylight.

If we now proceed to look for the causes of etiolation phenomena,[4] stress must be laid, above all, on the fact that, in consequence of their specific nature, the several organs of a plant are not equally influenced in their growth and formation by want of light. It is also to be remarked that want of plastic matter can not be the cause of etiolation, for we frequently see that it occurs in spite of the

[1] Godlewski, *Biolog. Centralbl.*, 1889, vol. 9.

[2] Sachs, *Botan. Zeitung*, 1864, p. 371.

[3] Vines, *Arb. des botan. Instituts in Würzburg*, vol. 2.

[4] Literature: Godlewski. *Bot. Zeitung*. 1879. Kraus, *Jahrb. f. wissenschaftl. Botanik*, vol. 8. Detmer, *Pflanzenphysiol. Praktikum*, 1888, p. 278. Frank, *Lehrbuch d. Botanik*, 1892, p. 896.

presence of abundant quantities of nitrogenous and non-nitrogenous bodies.

Etiolated over-elongated stalks differ from normal ones in several particulars, which deserve special attention in considering the question now before us. Of primary importance is the fact that the elements of which these stalks are formed, especially *Collenchyma*, bast, and wood, have relatively thin membranes, as I know from personal observation. The extensibility of these organs must, therefore, be remarkably great. Further, the quantity of osmotically effective materials contained in the cellular sap, especially organic acids, is, according to different observers, relatively large in stalks developed in the dark. Under such conditions the turgescent expansion of the cells must be considerable, for we have here a combination of great osmotic activity of the cellular contents (increased turgescent power), with a small resistance capacity of the membranes. There is a connection between this and the abnormal elongation of the cells of etiolated internodes (and probably also the abnormal increase in the number of cells), as well as the fact that internodes grown in the dark contain a greater percentage of water than those developed in the light.

While the cause of the over-elongation of etiolated internodes must be looked for in the over-elongation of the cells, as well as in the abnormal multiplication of the latter (between which phenomena there is surely a causal connection), it is, as yet, by no means certain what determines the smallness of leaf in dicotyledons grown in the dark. We may assume that the superficial growth of the leaf cells, and, therefore, in consequence of their reactive power, that of the whole leaf, proceeds normally in the light for the sole reason that only under such conditions is there formed, out of the plastic material present, a sufficient quantity of such bodies as are required by the protoplasm of the leaf cells, in order to develop its activity in a natural manner.

If young plants are exposed to a very intense light, this growth ceases entirely, as was found by Wiesner,[1] and it is not resumed until the light is lessened. Other conditions being equal, growth proceeds most rapidly in the dark.[2] This is the case, as a rule, with the embryonic parts, though there are exceptions. By taking into consideration the retarding influence of light and the accelerating effect of darkness, the phenomenon of the daily periodicity of growth, notably demonstrated by Sachs[3] for stems and by Prautl[4] for leaves, will also

[1] Wiesner, *Denkschriften der Akad. d. Wissensch. in Wien*, vols. 39 and 43.
[2] Sachs, *Lehrbuch d. Botanik*, 4th ed., p. 808.
[3] Sachs, *Arbeiten d. botan. Instituts in Würzburg*, vol. 1, p. 89.
[4] Prautl, *Arbeiten d. botan. Instituts in Würzburg*, vol. 1, p. 371.

become intelligible. The organs of plantlets exhibit this periodicity under normal conditions.

In the dark, *i. e.*, at night, the accretive motion of plants is universally more pronounced than during daytime. Light has a retarding effect on growth—a phenomenon which can also be demonstrated on leaves, that is to say, on organs whose development is greatly impaired if they are permanently kept in total darkness. But growth in total darkness and growth under the influence of the daily alternation of day and night are widely different conditions. The times of day for the maximum and minimum, respectively, of the accretive motion are not always the same for the several varieties of plants. Frequently the growth is most rapid in the early morning hours and least rapid during the first hours of the afternoon.

Of great biological importance to plantlets are the heliotropic nutations which they are capable of performing.[1] If the illumination is one sided, the hypocotyls and epicoptyls will curve toward the light in consequence of the more active growth of their darker sides, so that the luminous rays can be utilized to the fullest extent in promoting the assimilative functions of the leaves. Roots, in general, are either not at all or only feebly positively heliotropic. Some plants, however (those of many crucifers, for instance), produce decided negatively heliotropic roots, which, if receiving light on one side only, turn away from its source.

Oltmann's[2] more recent and very interesting labors, whose results I found to be partly corroborated by subsequent investigations, teach us that, contrary to the views heretofore universally accepted, heliotropic nutation is brought about and governed, not by the direction of the incident rays of light, but by the intensity of light.

The leaves of young plants—cotyledons elevated above the ground, as well as, for instance, primordial leaves—assume very definite positions under the influence of light. For the most part they so arrange themselves that the incident rays strike their surfaces at right angles. The motions which bring about this fixed position of the leaves have been the subject of many investigations, a detailed exposition of which would carry us far beyond the limits of this article. In spite of the doubts expressed by Vines, I still maintain that photo-epinastic motions participate in producing the fixed position of leaves as regards the light.[3] For the rest the reader is referred more especially to the detailed expositions of Schwendener,[4] which deal with these phenomena and with their causes.

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[1] These have lately been critically examined, notably by H. de Vries, Wiesner, Sachs, and Pfeffer.

[2] Oltmann's *Flora*, new ed., vol. 50.

[3] Detmer, *Botanische Zeitung*, 1882, No. 46.

[4] Schwendener, *Abhandlungen der Akad. d. Wissenschaften zu Berlin*, 1892.

## 3.—PHENOLOGIC OR THERMAL CONSTANTS.

Dr. Egon Ihne.

The problem relating to the thermal constants of vegetation has not made progress in recent years. The indefatigable exponent of this theory, Hermann Hoffmann, died at Giessen in 1891; since then observations of this nature have been suspended there. Of the numerous other stations where phenologic observations are conducted, only a very few include the question of thermal constants within the sphere of their investigations; among those which do are Uman and several other agricultural schools in Russia.

It is well known what methods were zealously recommended by Hoffmann. Beginning with January 1, as a day of vegetal rest, he added together the daily positive (plus) maxima of a thermometer fully exposed to the sun, up to the day on which the vegetal phase in question set in, as, for instance, the first blossoming of certain plants. From long-continued observations Hoffman reached the result that at Giessen the thermometric values (thermal constants, sums total of heat, or phenologic constants) obtained by this method coincided from year to year in a satisfactory degree. This held good primarily for ligneous plants and, be it added, for the same specimens. The values obtained by Hoffmann were so constant that he believed he had demonstrated, for Giessen, at least, that there existed between vegetal development and the supply of heat (as measured by the obtained values) a legitimate quantitive relation as follows:

Although the same vegetal phase may set in on a date varying from year to year, the date depending primarily on the climate of each year, yet to reach this phase the plant requires an amount of heat that is constant from year to year. A plant may therefore be considered as a means for measuring heat; and the beginning of a certain vegetal phase is also a standard for measuring a certain sum total of heat supplied up to that date, and this sum total expresses the measure of heat required by the plant to reach the phase in question.

The absolute magnitude of the sums total obtained by Hoffman for several plants and phases depends of course on the thermometers used, and has no significance for the question itself. Hoffman, in the course of time, made use of several kinds of thermometers, of different construction, such as common maximum thermometers and maximum thermometers with blackened bulbs in vacuo (Walferdin system). Different sums were, and must be, obtained with thermometers of different construction, but not so with the same instruments. Most investigators who have occupied themselves with the problem of thermal constants have, in their calculations, made exclusive use of shade temperatures, either the mean or the maximum

temperatures; and this is still the case at Russian stations. Further, some investigators obtained their sums total, not by simple addition, but by more or less complicated methods, which, however, need not here be referred to in detail. As a permanent result of Hoffmann's labors in this respect, it may be assumed that the insolation must be taken into account.

But all methods of paralleling vegetal development with thermometric values are open to numerous and legitimate objections. This is made very clear, for instance, in Drude's *Handbuch der Pflanzengeographie*, of which I have made extensive use in the following statement of objections:

Above all, stress must be laid on the fact that plant life, in its period of growth, is governed by the joint effect of the climatic factors, heat, light, and moisture, but that we are hardly able to reciprocally weigh their individual power. Further, that which causes our trees and shrubs to bud and blossom in the spring is not only a consequence of the gradual increase of heat, together with light and sufficient moisture, but these vegetal phenomena are also the effects of an obscure biological property, a certain interior rythm of the ligneous plants, by which they perform annually, with suitable periods of rest, the same functions in regular sequence. (See, among others, Wiesner's *Biologie.*) This rythm has adjusted itself to the average climate. Connected with this is the fact that the duration of the period of rest also exerts an influence on the development of vegetation, and, therefore, can not arbitrarily be shortened, so as to always produce by an artificial increase of temperature (hot houses), in a relatively short time, the same effect as that produced by a lower temperature continued through a longer period.

But it is so evident that in our districts (central Europe) vegetation is pre-eminently governed by the temperature, that we can readily explain why those investigators who have concerned themselves with thermal constants have selected heat alone, which is comparatively easily measured, from among all the factors that influence vegetation, and why they have searched for laws with thermometric values.

If, notwithstanding the above-mentioned objections, it is not desired to reject every justification of these methods, other important difficulties are encountered when the starting point of the thermometric reckoning is in question. This reckoning must, without doubt, begin from a natural zero point of vegetation. But where is this point in nature? With deciduous plants we may safely select the day of sowing similarly treated kinds of seeds; with our ligneous plants it should probably be the beginning of the period of rest or the beginning of vegetal activity. But the beginning of either period is very hard to determine; for phenologic observations have demon-

strated that the vegetal activity of buds does not entirely cease even during the winter period of rest (Askenasy). The first day of January, which has been selected in many methods as a day of complete winter rest, is therefore a somewhat arbitrary date, although the error is probably a small one. Drude suggests the date of the winter solstice, or the first day of December. Ziegler (Frankfort-on-the-Main), who otherwise follows Hoffman's method, reckons from the beginning of a vegetal phase in one year to the beginning of the same phase in the year following. Very noteworthy results have been obtained by him.

Further, as has been demonstrated by physiological investigations, it is not every temperature above zero (centigrade) that is effective in vegetation, but the degree at which the temperature begins to be effective varies for different plants and phases. In the simple addition of positive temperatures, be they shade means, shade maxima, or insolation maxima, this variability finds no expression. The zero point of effective temperature should first be determined for each phase and plant in question.

All these theoretical objections, as well as some additional ones of a practical nature, have induced many investigators to believe that they must relinquish the entire problem as impossible of solution. Nevertheless, the agreement of the thermal constants obtained in some methods, especially in that of Hoffmann, can not be dismissed by simply ascribing it to chance. But these results must probably be given a different interpretation.

We must abandon the conception that the summation of heat, which has been ascertained for a certain vegetal phase at any one locality, is a measure of the amount of heat which that phase requires; but it (the summation) must be considered as a measure of the amount of heat which that locality affords to the phase and to which the latter has accommodated itself. It is, therefore, not a relation of cause and effect, but one of accommodation that exists between sums total of heat and vegetal phases; and it remains now to determine whether of our thermometric measurements these sums furnish the suitable measure in which this accommodation is reflected. Drude, in his *Pflanzengeographie*, expresses the same opinion.

In the further prosecution of these investigations the following points should be kept in view:

An instrument, as nearly perfect as possible, should be contrived for the simultaneous measurement of light and heat; and the same style of instrument should be used at all stations of observations. Hoffmann, in his last notes on thermal constants (1890), has called attention to the sunshine recorders of Campbell and Stokes.

The starting point of the reckoning must be the same at all

stations. This may involve the error of neglecting the zero (or starting) point of effective temperature, but it will probably be found that the error is not of sufficient importance to render the results questionable. Here, it will have to be determined from observation whether the first day of January, or one of the dates proposed by Drude, or that used in Zeigler's method, is the best starting point.

As a fundamental condition, the values obtained at any one station must be constant from year to year for the vegetal stages in question, which should always be observed on the same specimens. When this has been demonstrated for several localities, the values obtained at the different stations for the same species can be compared one with another. It will most certainly be found that these values are not equal one to another; and it is probable that legitimate relations will be obtained concerning the capacity of different plants to accommodate themselves to the same climate, and the capacity of the same plant to accommodate itself to different climates, *i. e.*, the same relations which Linsser, as early as 1867, made a subject of investigations.

A more gratifying subject than an exposition on thermal constants would have been one on the present status of European phenology in general. But as that subject was not assigned to me, I will only refer to it briefly as follows:

Annual phenologic observations are now made in all European countries, excepting only the Balkan Peninsula, southern Italy, and Spain. Systems of observations have been organized, and reports are received by scientific societies and institutions, as well as individually, by some private persons (in Germany, the experiment stations of forestry and several meteorologic institutions). The reports are usually published once a year. The time of the first blossoming of the most-widely distributed woody plants is noted with particular frequency; next in consideration comes the beginning of foliation, the ripening of fruits, and the time when leaves change color everywhere. The beginning of the blossoming time (first blossoms) is the most readily observed phase. This and other vegetal stages are defined as follows in the "Instructions for Phenological Observations," by Hoffmann and Ihne (Giessener Schema), which have been followed by many observers since 1881:

Foliation, first leaves unfolded; at different (2 or 3) places.

Blossoming, first blossoms open; at different (2 or 3) places.

Maturity, first fruits ripe; at different places. With juicy fruits the sign of ripeness is a perfect and definite change of color; with capsular fruits, a spontaneous bursting of the capsules.

Color change of foliage; more than half the leaves of a locality have changed color, including leaves already fallen.

In order to obtain uniformly comparable results, it is necessary that the observations be made under normal conditions, *i.e.*, on average standard specimens, under normal (not extreme) exposure; otherwise there is danger of noting an exceptionally early or exceptionally late specimen. It lies in the nature of the matter that in noting the phases it is not absolutely necessary to observe the same specimens in each year.

Instructions from other sources are, for the most part, to the same effect; and it may be said that the basis of all phenology, to procure accurate and intercomparable observations, is steadily being extended and improved. There is also a close conformity of the observations of the present time to the best observations of the past, above all to those which were prompted by Quetelet (Brussels) and Fritsch (Vienna). The present observation system of Finland is in close touch with that which in times gone by was originated by Linnæus, the founder of phenology.

A detailed history of the European observations, with a catalogue of other works, was published by Ihne, at Giessen, in 1884. To what extent phenologic observations are systematically made in the United States is unknown to the present writer.

There is also no lack of works in which the recorded phenologic data have been utilized in various directions, both in a biologic sense and in the direction of geographic climatology. I can not enter into details at this time, and will only make special mention of the fact that the last-named subject (geographic climatology) has received the largest share of attention, and that we already have phenologic charts of Europe and of several European countries. We may confidently hope that the development of phenology will continue in a satisfactory manner.

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## 4.—SOME INTERRELATIONS OF CLIMATOLOGY AND HORTICULTURE.

Prof. L. H. Bailey.

Climatology concerns the agriculturist in two general directions—in aiding him to anticipate the condition of the weather some hours or days and thereby enabling him to plan his work with confidence, and in explaining the climate of any place in such manner that he can determine its probable influence upon a prospective business. The former office is the one which most readily appeals to the masses, and its direct result is prognostication, which, to most persons, is the only expression of the science. However valuable prognostication may be to the mariner and the general farmer, it serves the horticulturist very little; and its uses are everywhere transient. But local

climate exerts a most powerful influence upon the plants which one attempts to grow. In short, it interposes a bar somewhere to the cultivation of all species, and becomes, therefore, the controlling factor in every scheme of rural industry. I speak of local climate, and not of any mere influence of latitude, longitude, or altitude. The climatal limit of any crop, in all directions, is an exceedingly irregular one, presenting a series of sharp curves; that is, the local variations of climate determine the distributions of cultivated plants. Now, it is true that crops are usually valuable in proportion to the difficulty of their successful cultivation, for only the best cultivators can succeed in such regions, and demand is thereby lessened. This is especially true of those products which are very perishable or for which there exist strong home demands; and these attributes apply particularly to horticultural crops. The horticulturalist, therefore, is vitally interested in the climate of his particular neighborhood; and it is the study of this local climate in its relations to plant life which must bring him the greatest good from climatological science.

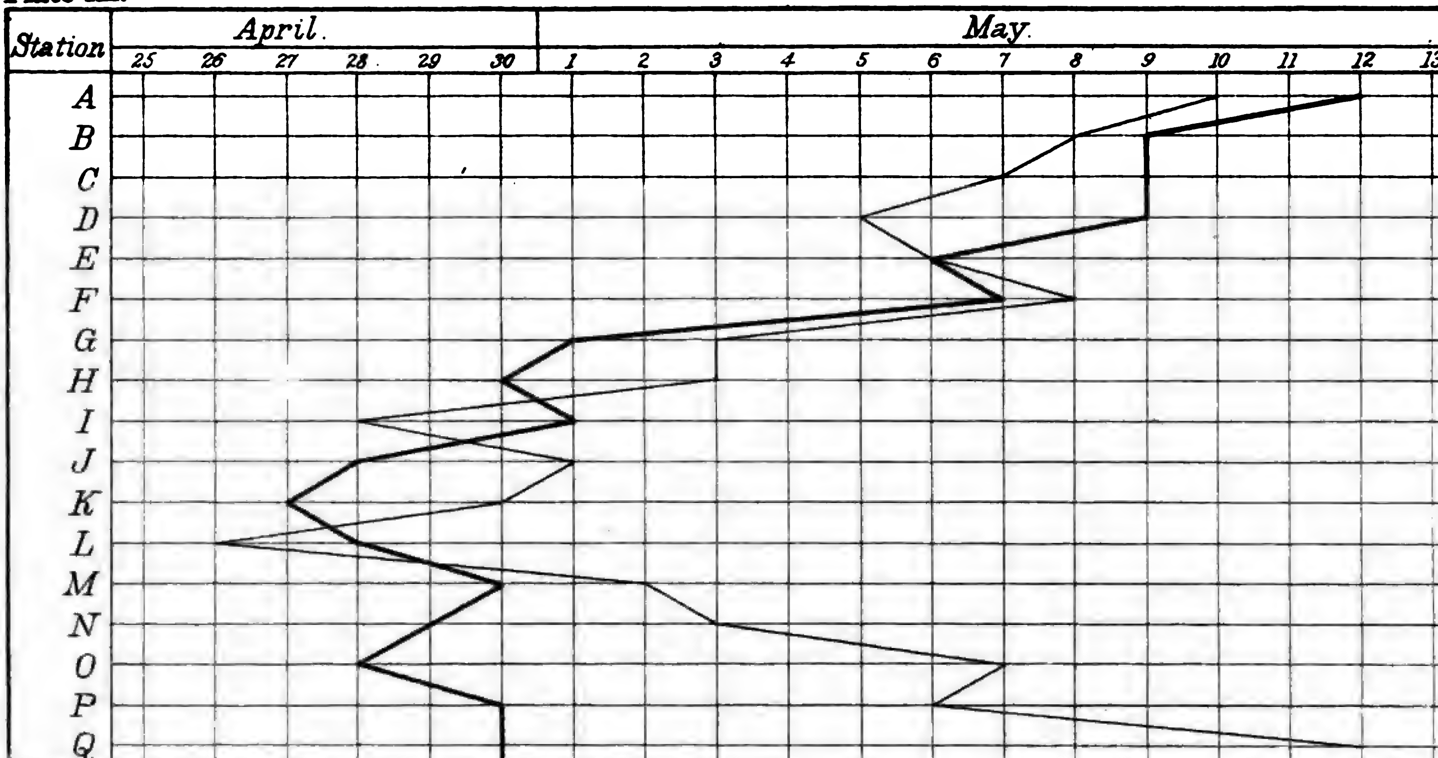
If the horticulturist is concerned more with climate than with weather, it follows that meteorological records, to be of use to him, should be expressed in terms of plant life rather than in terms of degrees of temperature or other numerical standards. Very good records could be made by an army of careful growers who had neither a barometer nor a thermometer. Let us suppose, for instance, that the peach growers of a certain geographical area were to make observations for a number of years upon the relative synchronisms of late frosts and blooming time, a subject which is of the most vital importance to every grower of the tender fruits.

The tabulation of these observations would enable us to construct two series of curves, which would indicate at a glance the comparative safety of any station for the cultivation of the given crop. We will suppose that observations have been taken for a number of years by various persons at seventeen closely connected stations, represented by the letters in the margin of Plate XI. One curve represents the date of the last killing frost, and the other the date of the opening of the peach flowers. Wherever the frost line lies beyond the bloom line, as in the first five stations, peach growing is impossible. When it lies at the left, peach growing is possible, and the industry is safe in proportion as the two lines diverge. At the stations I, K, and O peach growing may be considered to be far beyond danger of late frosts. These tabulations would be valuable, of course, in proportion as they include a minute record of every farm in the given territory; but even a somewhat superficial series of observations would possess great value if accurately made, as indicating the probable influence of local climate upon the given industry. If lines tend to converge, or if the frost

Plate XI.

## Synchronistic Tabulation of the Last Killing Frost and the Blooming Time of the Peach Tree.

(Heavy line represents Frost, and light line Blooming time.)



line crosses beyond the bloom line, there is indication, at least, that safe peach lands are few in those localities. The information which these records ask could be well ascertained from observations upon a few peach trees here and there long before any general experiment of cultivation had been tried.

There are no doubt many regions of the north, which are now almost devoid of peach orchards, which could yield profitable fruit lands if persons could feel sure that there is comparative immunity from late frosts; and inasmuch as fruit growing is one of the most profitable and pleasant of rural pursuits, it follows that the meteorological bureaus could here perform an inestimable service for the agriculture of the country. Even in the older parts of the country information of this kind would find ready use, for none of our States are yet developed to even a quarter of their capabilities for fruit growing.

Old lands which have been farmed over and have lost most of their value for grain and stock may still be invaluable for fruits and other horticultural crops; but fruit growing reaches them very slowly and hesitatingly under ordinary circumstances. Even in regions which have once been devoted to fruits there may come a real or apparent change of climate, which overturns the business of the community. An instance of this kind occurs on the eastern shore of Cayuga Lake, in New York. This shore was a well-known peach region a generation and more ago, but the old orchards have now disappeared and new ones do not take their places, because the people feel that some change of climate within the generation makes peach growing more precarious than it was formerly. Orchards are creeping in slowly here and there, but everyone is distrustful. Similar instances are common in many parts of the country, and the services of climatology should be called to the solution of the difficulties.

What I have said of the synchronisms of frosts and blooming periods can be repeated with almost equal force for many other attributes of climate in their relations to plant life; and these observations will apply to all fruits, besides peaches, which are liable to injury from late frosts. It will be found, in fact, that even different varieties of the same species may demand separate treatment, for these often vary among themselves in time of bloom, quite as constantly as in time of maturation of fruit. The synchronisms of early fall frosts and maturation of certain fruits are subjects of immense importance to the horticulturist. The northern limit of grape culture, for instance, is determined much more by the date of early fall frosts than by winter climates. This is well illustrated by the Catawba, which is our most important native wine grape. It hugs the shores of certain lakes in western New York so closely that the majority of New York grape growers are unfamiliar with its cultivation and fear that its area can not be greatly extended with safety;

yet there are undoubtedly enough isolated Catawba vines in most of the fruit regions of the State to enable observations to be made for a term of years, and which might give rise to a reliable monograph of the climatal limitations of the variety within the State. Even the cloudiness of winter months is an important consideration for those who force plants under glass and who must economize every particle of sunlight in order to bring the plants to maturity quickly and cheaply.

I am, myself, located in a district so cloudy that forcing of vegetables is scarcely profitable, and if I were to engage in the business commercially, I should seriously consider moving a few miles away into a sunnier area. With the increasing complexities of the future and the niceties which must then be practical in order to make rural occupations profitable it will be necessary to construct charts of cloudiness with special reference to horticultural pursuits, for not even the electric light can be expected to stand for normal sunlight.

Winter and summer climates should be studied in terms of plant life quite as much as measured by the customary instruments, for plants record all the influences of climate, while the instruments measure only detached attributes. It follows that the contemporaneous effects of seasonal climates can not be studied upon the wild plants of a region, for these plants have long since overcome the difficulties of the particular climate, or are acclimatized. Cultivated plants, which have been brought in from other climates, must, therefore, be chosen as the registers of the meteorological peculiarities of a given region. We need charts giving the zones or life areas of the cultivation of the different fruits, and these zonal limits should be constructed from the actual behavior of trees in winter, or in summer, rather than from any assumed theoretical temperature at which trees perish. If constructed from the orchard observations, these limits would become much more than mere isotherms, for trees may be injured quite as much by the alternations of temperature, the relative humidity of soil and atmosphere over great areas, the direction and force of prevailing winds, and other features, as by temperature itself.

There are numerous problems of still more local application which are yet of vital importance to the cultivator and in the solution of which he has the right to expect the aid of the climatologist. The habitual force and frequency of winds during the seasons of maturation of fruits, the prognostication and methods of averting frosts, the influence of wind breaks and orchards upon local climate, the modification of climate in consequence of the removal of forests and the clearing of land, the frequency of droughts, the humidity of atmosphere as affecting the spread of fungous diseases, and the ability to prognosticate serious incursions of these diseases, from a study of

their general relations to climate, the liability to hail storms, the nature of the seasonal variations—these, in addition to the subjects which I have already indicated, are some of the living problems which await us.

Thus far, I have spoken only of what may be considered the immediately and intensely practical side of horticultural climatology. It will occur at once to the student that these very observations which I have suggested will afford data for the study of all that fertile subject which concerns the interrelations of climate and plant life in the evolution of the vegetable kingdom, and it opens the whole field of plant variation and distribution in its relation to environment. Every plant is profoundly modified by the climate in which it is placed; and if any species, therefore, is cultivated over a wide range of territory we must expect to find it widely variable between the extremes of distribution. The same variety of apple, for instance, may lose all its distinguishing qualities and marks through a simple transfer to climates not far removed. A study of the statistics of apple exportations during the next ten years will probably show what States or districts produce fruits of sufficient firmness and long-keeping qualities to withstand the journey profitably. And it is not too much to ask of climatology that it shall tell us why the northern climates develop saccharine elements and high colors, and why the Wisconsin-Minnesota area produces such remarkable waxen and pruinose tints. The influence of climate is nowhere so easily traced, perhaps, as in the business of seed growing. Every seedsman knows that certain climates are not only best adapted to the growth of certain seed crops, but that they exert a profound influence upon the character of the product grown from them. The study of all these interrelations of climate and plant life falls into three subjects: Phenology, or the study of the periodic phenomena of plants, a subject which loses half its force and value when considered, as it usually is, without reference to the visible attending features of climate; acclimatization, or a consideration of the means by which plants adapt themselves to climates at first injurious; and secondary variation of plants induced by climatal environment.

The burden of my plea is twofold: First, while not discouraging the instrumental or conventional study of climate, I would encourage its study in terms of plant life. Second, it is essential that the synchronisms of local climate and the phenomena of plants be given the closest attention.

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## 5.—WINDS INJURIOUS TO VEGETATION AND CROPS.

GEORGE E. CURTIS.

Wind is not one of the meteorological elements which, in general,

plays a primary and essential part in the growth of vegetation. We recognize rain, heat, and sunshine as the indispensable elements of climate, upon which most plant growth depends, and only in the case of the *Coniferæ*, the grasses, the fedges, and a few other species of plant life does the wind rise to the front rank and become also a necessary condition of existence. For these plants, called anemophilous, the wind performs the important service of transporting their pollen, and thereby becomes the essential external agent in their fertilization and reproduction. But while the wind, except in these cases, is not one of the beneficient meteorological agencies upon which vegetation, and especially cultivated vegetation, depends for its fertilization, growth, or fruitage, at times it plays an entirely overshadowing part as a destroyer. The violent gale or the benumbing blizzard may ravage the tender orchard as ruthlessly as disease or drought, and the desiccating wind may blight the growing grain as irremediably as fungus or frost.

The classification of injurious winds, the determination of the regions and seasons of their occurrence, the examination of their characteristics, and the investigation of means for the mitigation of their effects and for protection from their ravages, become, therefore, important subjects of economic meteorology. This study is especially attractive because it seems probable that over vast areas, by properly directed effort, we can obtain protection and immunity from winds to a greater extent than from the effects of any other injurious state of weather. No plausible rainmaker can dissipate drought by drawing showers from out of a cloudless sky, but where irrigation can be practiced the farmer no longer has need of rain. In seasons of excessive rain the downpouring waters can not be stayed, but by suitable systems of drainage something can be done to dry out the soil. Against the occurrence of extremes of temperature there is no recourse, but by smudges the damage that would be done by an untimely frost can often be averted. Likewise, although the occurrence of destructive winds can not be entirely prevented, we may set nature to build a protecting barrier that will materially mitigate their effects.

It is the object of the present paper to make a brief survey of the principal winds destructive to agriculture, describing the salient features which they present, and to determine from the data thus collected what may be efficaciously done toward diminishing the destruction that they cause.

For our present purpose most destructive winds may be placed in one of the following classes:

1. Violent winds.
2. Cold winds.
3. Hot desiccating winds.

A few injurious winds may be found that do not properly fall in any of these classes, but they are in general not of great importance to agriculture. Thus, for example, seacoast storm winds, impregnated with salt, occasionally blight all vegetation for a distance of from 1 to 2 miles inland, an effect due not to their temperature or violence alone, but principally to the salt which they contain. It is partly from this cause that coasts subject to storms possess but a scanty and stunted growth. Such coast winds affect, however, only a limited area, and do not possess any great economic importance.

### VIOLENT WINDS.

This class includes all winds that injure or entirely destroy crops and fruit by their force alone. In the United States the tornado, the derecho, and the West-Indian hurricane are the most violent of such storms, but as they occur only over limited areas, or at very long intervals, their aggregate damage to fruits and crops is much less than is caused by the winds which frequently accompany local thunderstorms and by the severe gales which often prevail during the passage of intense general storms. I do not know of any agricultural region that has an absolute immunity from such high winds and gales, but some regions are, on the average, more disastrously affected than others. Undoubtedly the region of greatest destruction by violent winds in the United States is the great plains region, from Illinois westward to the boundary of cultivation. During the past season of 1893 the winter wheat of Kansas has proved almost an entire failure in many sections of the State, due in large measure to the violent winds of late spring. The greatest destruction is effected when such winds prevail at a late stage of the ripening grain; for then the heads are threshed out by the beating winds, and nothing is left to the farmer but the empty stalks.

### COLD WINDS.

Winds injurious to vegetation by reason of their low temperature are comprised mainly in two of the classes into which winds are ordinarily divided by meteorologists, viz, (*a*) mountain and valley winds; (*b*) anticyclonic winds, or northerly winds associated with and following cyclones.

Mountain and valley winds do not occur to any marked extent in the United States, and where they do occur there is generally very little vegetation to be injured. In parts of Europe, however, especially in Germany, cold valley winds, of which the Wisper wind of the Rhine is a notable and typical example, are exceedingly injurious to the vine and other tender fruits, and limit the area of their cultivation.

The second class of cold winds includes those called blizzards and northers in the United States and the mistral and bora of southern

Europe. These occur mainly during the winter season, when there is little agriculture to be damaged; and the fruit orchard is the principal victim of these piercing blasts. The low temperature alone would not prove disastrous, but it is the wind which renders the cold penetrating and destructive. These cold winds are the principal enemy of the tender peach and determine the limit of its successful cultivation. A remarkable example of their effect is to be found in the climatic history of Michigan, where a half century ago peach trees flourished and were rarely injured by the cold; but after the lumberman began his work of deforestation Dakota blizzards made greater and greater inroads into the State, the tender peach trees were killed along their path, and now the peach crop has nearly disappeared. From the same cause the attempt to grow peaches in northern Kansas has been largely abandoned. Cold winds are, moreover, not always confined to winter, and the greatest aggregate damage done by them is when a belated blizzard occurs in the spring after the various crops have started and when all fruit trees have put forth their shoots and buds. Every year the Monthly Weather Review contains reports of greater or less damage caused by these late and unseasonable visitors.

### HOT DESICCATING WINDS.

The third and last class of winds injurious to agriculture are those characterized by intense heat and dryness. To the meteorologist they are the most interesting of all these classes, both on account of their physical characteristics and the devastating effect produced. These winds, according to the location of their occurrence, may be broadly divided into two groups, the hot winds of the plains and the desiccating winds of California (including portions of Oregon and Washington).

Before passing to the description of these two groups, a few words should be said with respect to the Chinook winds of the east slopes of the Rocky Mountains, which have the same characteristics of heat and dryness. These occur principally in the winter season, when the only vegetation affected consists of grasses and trees. They are essentially warm westerly winds which interrupt the severity of winter and by their combined warmth and dryness evaporate the snow without melting it. From this effect, they are locally termed "snow-eaters." Upon the dried grass of the stock ranges their effect is highly beneficial; moist thaws would take its virtue from it, but the dry thaws make it accessible to cattle without injuring it as cured hay.

The extreme dryness of the Chinook is injurious to trees, especially to conifers, which are very sensitive in their dependence upon a humid atmosphere. Hence, the Chinooks are considered by some to be an important cause of the treelessness of the eastern slopes of the

Rocky Mountains, where the western slopes are covered with heavy timber. Although most noticeable in the winter, the Chinook also occurs through the spring and early summer, when agricultural crops are then affected. Chinooks in May and June frequently damage wheat and other crops, and, therefore, become at that season injurious to agriculture. During the past season the Colorado Weather Service reported such injurious hot winds as occurring in the agricultural districts along the eastern base of the mountains, from the northern boundary of the State southward to the Divide, or to about the thirty-ninth parallel of latitude.

The *hot winds of the plains* occur over a vast agricultural area and in some seasons do incalculable damage to all crops, and especially to wheat and corn which cover the greatest acreage. The area over which they prevail extends from Dakota to Texas; in occasional seasons they occur east of the ninety-fifth meridian, but their greatest frequency and severity is westward of that meridian to the boundaries of cultivation. The season of their occurrence continues through the whole summer from about the first of June to the middle of September. An illustration of their destructiveness to agriculture may be drawn from the statistics of ten Kansas counties in 1888 which showed a loss of 21,000,000 bushels of corn alone, due principally to hot winds.

In 1889 the present writer, astonished by these statistics, made a special investigation of the hot winds of that year in co-operation with the Kansas Weather Service. Special reports were obtained through the aid of voluntary observers, and from the data thus collected the characteristics and effects of the hot winds were summarized as follows:[1]

*Direction.*—Hot winds are usually from the southwest, coinciding with the direction of the prevailing summer winds of middle latitudes; less frequently from the south or even southeast, and very rarely a hot wind may be experienced from the north.

*Time of occurrence and duration.*—Hot winds occur most frequently in July and August, but occasionally also in June and September. A period of hot winds very generally continues for about three days over extensive areas, and these winds have sometimes been reported to occur daily for two weeks with greater or less severity.

The typical hot wind almost invariably sets in at 9 or 10 o'clock in the morning and continues until 5 or 5.30 in the afternoon, when the peculiar heat is abated, although the wind may continue through the night with unabated force.

*Temperature.*—In the six hot winds reported by the special observers in 1889, temperatures ranging from 100° F. to 109° F. were experienced.

*Humidity.*—The extreme dryness of the hot winds is one of their principal characteristics. It seems probable that the average relative humidity is not higher than 20 or 25 per cent, but no hygrometric observations have been made by our special observers.

*Wind force.*—The force of the different hot winds reported ranged between wide

[1] George E. Curtis: "The hot winds of the plains." Seventh biennial report of the Kansas State Board of Agriculture. Topeka, 1891; pp. 162–183.

limits. In some cases the wind was only a "moderate breeze," while in others it was a "strong wind," and in one case it ranged from a "high wind" to a gale.

*Evaporating power.*—The high temperature, the dryness, and the velocity of the hot winds constitute all the factors that promote evaporation, and the resulting rate of evaporation under their influence is consequently exceedingly high. No quantitative measures of the rate of evaporation during the hot winds are, however, yet at hand.

*Effect on vegetation.*—In rare cases hot winds may scorch and burn vegetation while there is still moisture in the soil for the plant to draw upon to replace that which transpires. Wheat, when in the milk, and corn just beginning to tassel or to ear, are in critical stages, and are especially liable to be injured by hot winds. But, in general, hot winds do not materially affect the crops until by their evaporative effect they have drained the soil of its moisture. Before that vegetation droops and wilts somewhat during the day, but recovers at night, and upon the cessation of the hot winds is generally found to be not seriously damaged. But when the hot winds and lack of rain have thoroughly dried the ground, then one or two days of hot winds wither and shrivel up the crops beyond possibility of more than partial recovery.

An attack of hot winds is usually found to leave some fields in much worse condition than others, and careful observation seldom fails to reveal the cause of the difference. All circumstances that conduce to diminish evaporation are most potent factors in preserving a crop of corn or wheat through a trying period. Freedom from weeds, deep plowing, and frequent cultivation which break up the capillary ducts in the soil, a sandy rather than a clayey surface soil, a subsoil of hardpan which stores up the rain waters for the crops to draw upon in critical periods—these are some of the conditions which diminish the rate of evaporation and delay the beginning of the drought. The contrasted effect of hot winds on two adjacent fields may generally be traced to a difference in one or more of these conditions.

*Relation to barometric pressure.*—The weather maps and statements accompanying the hot-wind reports for July and August, 1889, show the distribution of pressure during hot-wind periods. In every case an area of low pressure exists to the northward of the region of hot winds, and generally the pressure decreases to the British boundary. In most cases both the wind directions on the weather map and the reported directions of the hot wind conform to the configuration of the isobars. In no case is there reason to suppose that the direction of the hot wind is inconsistent with the local gradients of barometric pressure.

It appears, therefore, that in direction and velocity the hot winds are entirely normal, their direction conforms to the surface pressure gradients, and their velocity is not markedly different from that of the usual winds prevalent on the plains.

The most significant fact determinative of the origin of these hot winds is the notable diurnal periodicity which they exhibit, rising from 9 to 10 o'clock in the morning and continuing until 5 or 5.30 in the afternoon. Any hot wind having this characteristic is of local origin, and is not transported from a distant source of heat. Neither is it like the Chinook, a downpour of dry air heated dynamically in descending, for such winds exhibit no diurnal features, but set in at any hour of day or night. The diurnal character of the hot winds suggests and confirms the view that the local heating of the surface is the cause of the hot winds and furnishes the source of their high temperature. Kansas and Dakota each develops its own hot winds and can not charge them to the account of its neighbors.

Let us take a typical hot wind and examine in detail the process of its production. As already stated, the necessary condition is a diminishing pressure to the northward, producing southerly winds which initially elevate the temperature above the normal. A cloudless sky favors an intense insolation, as a result of which the dry ground is soon raised to an extreme temperature, and the air is heated from it by radiation, reflection, and conduction. The resulting diminution of density due to the rise of temperature furnishes impetus to previously existing horizontal currents, and by 10 o'clock in the

morning the hot wind is fully developed. Hundreds of miles of hot, dry earth contribute to maintain and feed the current, and gathering strength as the sun mounts higher, the hot wind sweeps over the defenseless prairie. Neither hills nor forests rise in its path to break its power or dispute its sway, and with no enemy save the tardy rain cloud, the fetid blast sucks out the life-sap of the growing grain. Thus, the crops which should have returned a harvest to the farmer in repayment for his toil are desiccated and withered in a day.

The surface soil is heated to the high temperature necessary to the development of hot winds only where the ground is dry. The sun's heat falling on a moist soil is largely used in the work of evaporation, whence the accumulation of heat and the rise of surface temperature, which would take place on a dry surface, is to a great degree prevented. In support of this, we find that the hot winds do not arise when the soil is moist, and that a rain storm quickly brings them to an end. Conversely, the reports bear uniform testimony to the fact that periods of droughts are periods of hot winds, and the more prolonged the more continuous and intense do they become. All methods of cultivation, which directly or indirectly help to increase or retain the moisture in the soil, will tend to ameliorate both the hot winds and their effects. As long as fields contain moisture to evaporate, they neither originate hot winds, nor can their vegetation, in general, be severely damaged by those elsewhere developed. Thus, every inch of water in the soil helps to postpone the development of hot winds, and affords a protection against their ravages.

In some instances hot winds may occur in which the diurnal feature is not presented, and when all the phenomena, taken together, appear to indicate that the wind is heated dynamically like the Chinook. Mr. I. M. Cline, of the Texas Weather Service, describes a hot wind of this character which prevailed over Texas, May 29 and 30, 1892. The intense heat traveled in narrow currents, ranging from 100 feet to half a mile or more in width, making their appearance on the 29th, about 2 p. m., in western portions, and about 6 p. m. in eastern portions of the State. The most intense heat was experienced on the afternoon and during the night of the 29th. These hot currents were apparently downpouring masses of dense dry air heated dynamically in descending.

A most notable feature in connection with these winds is that none of the heated currents were observed in the vicinity of timber.

### THE HOT WINDS OF THE PACIFIC COAST.

Similar in effect to the hot winds of the plains are those of the Pacific coast. These occur in the Sacramento and San Joaquin valleys of California and to some extent in portions of Oregon and Washington. In California these winds are northerly and are often designated as "the desiccating north wind." In Oregon and Washington, however, their direction is east, or from east to north. In a valuable article, entitled "Weather types on the Pacific coast," Lieut. Glassford found that these northerly winds occurred when an area of high pressure prevailed over Oregon and Washington, with a permanent low area over southern California, and designated this distribution of pressure as the "North Pacific anticyclonic type." Describing it, he says: "During its prevalence in its perfection and greatest intensity,

and while the isobars are perpendicular to the coast line, is the time when the dreaded desiccating 'north wind' prevails in the Sacramento and San Joaquin valleys." The greatest injury is done when the north wind occurs in May and June, during the periods when the great California wheat crop may receive incalculable damage. The manner in which wheat is affected by the hot wind is carefully stated by Hon. W. A. Shippee, of Butte County:

There are two stages when the grain is injured by these winds. The first is when the grain is in blossom, which is from the 1st to the 10th of May. The effect at that time of a hot north wind is to blast the blossom and no kernel forms. The heads puff out, but it is all husk and no grain. This seldom happens, for we rarely have hot winds so early in the season. Once we lost a partial crop by the north wind injuring the grain while in bloom. The second stage when grain is readily injured by the north wind is when it is filling or hardening, or in what is termed the "dough." The effect of a hot norther at that time is to kill the vitality of the stock, and no sap goes into the kernel to fill it and make it grow. The kernel, therefore, shrinks and does not become plump and full. The effect, however, depends upon the exact condition of the grain. One field may be just right to injure, while another alongside of it may not be hurt at all, as the grain may be less or further advanced.

The enormously destructive effects of a severe north wind in June is described as follows by Lieut. Glassford, in a published letter to Joaquin Miller, dated January 18, 1887:

Last year, up to June, the prospect for a large wheat crop was said to be never better. In this month [June] came a severe north wind, and the wheat anticipated diminished at once millions of centals. It was late in the season, the wheat was ready to cut, and it was found in this case that it was not altogether the drying up of the wheat, some being in the milk, but as well the thrashing or shelling out of the grains from the ripe heads, done by the severe wind presumably whipping the heads together. Upon sure investigation it was found that a field on the south side of a stream running westward, and that was skirted by a growth of tall trees, was not so much damaged as the field on the north side.

During the past season (1893) hot north winds that injured grain were reported from Siskiyou, Sacramento, Yolo, and Solano counties.

In Oregon, as in California, the hot winds are especially injurious in June. Then the dry wind shrivels up the fall wheat, which is in dough, while spring wheat is stunted and burnt brown. Mr. B. S. Pague, of the Oregon Weather Service, states that "three days of hot east winds reduces yields from 30 bushels per acre to wheat not fit even for hay. The character of the wind is abnormal dryness, in force from 6 to 15 miles per hour, and accompanied by temperatures of from 75° to 90°. The dry wind continues during the night, abating some, while the temperature has its diurnal change."

## MEANS OF PROTECTION.

At the beginning of this paper it is stated that the study of injurious winds is made especially attractive from the fact that to a greater extent than in the case of other climatic evils we may ameli-

orate and diminish their destructive effects; and throughout the data that have been here collated, the observed efficacy of timber belts as a wind break for the protection of orchards and crops, and the historic lessons of deforestation constitute an inseparable part of the story. The California fruit grower has been among the earliest to recognize this function of timber, and around many of the citrus groves of southern California may now be seen rows of *Eucalyptus* or other trees for wind protection.

The great western plains offer the greatest sphere for the operation of timber as wind breaks, for this is the natural home of all the destructive winds. California may be subject to hot winds and other regions to cold winds, but the western prairies are subject to them both. Here the winds are not only the most important climatic condition, but the one alone whose effects we can expect to materially modify. Writing upon this subject, Dr. Fernow says:

> The most potent influence which we must consider in the plains is the mechanical obstruction which a forest area offers to the passage of the winds, and the consequent reduction in the rate of evaporation. To see the prairies and plains, is to know their needs; to travel over them for a day, is to feel their want and to appreciate the value of a tree growth. Wind swept every day, every hour of the year, the wind break of even a single row of trees is a relief. The hot winds of summer and the cold blasts of winter both sap the moisture out of the soil. It is the rapid rate of evaporation induced by these winds that injures crops and makes life uncomfortable. Whether the forest aids in increasing precipitation there may be doubt; but nobody can say that it does not check the winds and the rapid evaporation due to them.

Many attempts at tree planting on the western plains have met with poor success because they have been improperly conducted. The aridity of the climate requires that suitable varieties be selected and properly combined, that a sufficient mass of foliage be obtained to create favorable conditions for growth, and then that the trees should not be left to themselves, but should be as thoroughly cultivated as any crop of grain. Sufficient experience has now been attained to demonstrate that, when these conditions are observed, timber strips can be successfully grown in Kansas as far west as the one hundred and first meridian, or beyond the present boundaries of successful agriculture. The last report from the Experimental Station at Garden City, in western Kansas, states that the timber strips planted for wind breaks have made a marvellous growth.[1] These strips consist of 4 rows of black locusts bordering all sides of a 160-acre lot, and several rows of cottonwoods on one side of an 80-acre lot.

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[1] Of the 2,200 trees planted around the 160-acre lot, as a wind break (in 4 rows), all are living and made a marvellous growth, except about 50 trees, which were completely destroyed by grasshoppers. The trees have been thoroughly cultivated during the season, and were mulched this fall with a layer of rye straw about 1 foot thick.—*Report of Secretary of Agriculture*, Washington, 1892, p. 206.

The protective effect of standing timber as an obstruction to the wind being recognized, it is important to know to what distance this protection is extended. The extent of the protective action of a vertical obstruction is accurately exemplified by the distance to which a snowbank extends on the leeward side of a fence. This is the width of the protected strip and we desire to know its ratio to the height of the obstruction. Mr. Barnard, of Pawnee County, Nebraska, and Judge Whiting, of Iowa, are authorities for stating that the protection amounts to 1 rod (16½ feet) on the ground to every foot in height of the protecting trees. Other writers give a somewhat less ratio for the distance of protection, but an average estimate is that a solid belt of trees creates a calm area on its leeward side which is, at the ground, from eleven to sixteen times as wide as the height of the trees.

Observation also indicates that barriers and obstructions, like buildings and trees, diminished the general velocity of the surface wind, beyond the limits of their immediate protective influence. These data, therefore, lead us to believe that if timber strips are planted at distances apart not greater than a half mile, or in other terms, if every 160-acre lot is surrounded by a belt of trees like that at Garden City, a very considerable protection will be afforded to the entire acreage.

If the plains of Kansas were cross-sectioned by such timber belts, platting the state into 160-acre lots, the blizzards and the hot winds that now possess an unobstructed passage would be stayed in their course, their blighting and desiccating effects would be largely diminished, and thereby a long step would be taken toward that climatic amelioration which alone is wanting to make a large part of the prairie a veritable garden spot.

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## 6.—DROUGHTS AND FAMINES IN INDIA.

JOHN ELIOT.

The subject which was proposed to me was "Droughts and Famines." I have thought it would be most satifactory if I limited the scope of the subject to that area for which I have ample information.

A drought is a more or less prolonged withholding of the usual or normal rainfall from large areas. Droughts of short period, varying from a few weeks to two or three months, are not uncommon over the greater part of the land area of the world. Droughts of long period are of comparatively rare occurrence. When they happen over densely populated areas almost entirely devoted to agriculture, they result in more or less widely spread famines.

The areas most subject to prolonged drought are chiefly included

within the tropics and the tropical belt in which the rainfall is periodic. Prolonged droughts are, on the whole, more frequent in India than in any other large area on the earth's surface. In order to understand the larger features of periods of drought and famine in India, it is necessary to point out the more important features of the distribution of rainfall in India and of the character of the crops as determined by the amount and distribution of the rainfall throughout the year.

The whole of India, the Malay Peninsula, and the adjacent seas, the Bay of Bengal, and Arabian Sea form an area which may be termed the Indian Monsoon Area, the chief meteorological features of which are indicated by the division of the year into two periods, viz, the northeast monsoon, or period of dry-land winds and continental meteorological conditions, and the southwest monsoon, or period of humid sea winds and insular or maritime meteorological conditions.

The former lasts from January to May and the latter from June to December. They overlap to some extent, as the change from the one to the other does not occur at the same date over the whole of India, but is a more or less gradual process.

The southwest monsoon lower air circulation is a northward extension of the southeast trades of the Indian Ocean across the equator, and is determined to India and Burmah by special conditions in that area. The determining conditions are undoubtedly the formation of a deepish low pressure area over northern India (and perhaps central Asia, although this appears to me doubtful) in April and May due to rapid increase of temperature. The extension is not, however, the final result of a gradually increasing indraught to the hot area in northwestern India. As has been abundantly shown in the more recent publications of the Indian Meteorological Department, it occurs as the more or less breaking down of the southeast trades circulation at its equatorial limits and the more or less sudden adaptation of that circulation which has been developed for some weeks previously to new conditions. The extension of the southeast trades and the establishment of the southwest monsoon currents commence at the equatorial belt in May, and a circulation of a different order of intensity, volume, and other characteristic features from that previously existing in that area, is more or less rapidly established over India in the month of June as the result of the extension. It is maintained for a considerable period, not by the continuance of the hot weather conditions in upper India, but mainly by its self-contained energy liberated by rainfall during its existence over India.

The following table (Table I), which gives mean data for the larger provinces of India for the months of May and July, shows the character of the changes due to the advance of the current over India in June:

TABLE I.

| District. | Normal mean monthly 8 a. m. pressure (reduced to sea-level and constant gravity) at latitude 45°. | | | Average monthly maximum temperature. | | |
|---|---|---|---|---|---|---|
| | May. | July. | Change. | May. | July. | Change. |
| Burmah | 29.777 | 29.718 | —.059 | 92.8 | 85.2 | — 7.6 |
| Bengal and Orissa | 29.703 | 29.558 | —.145 | 93.6 | 88.5 | — 5.1 |
| Behar and Chuta-Nagpoor | 29.665 | 29.535 | —.130 | 98.3 | 89.2 | — 9.1 |
| Northwestern Provinces | 29.644 | 29.510 | —.134 | 104.0 | 91.7 | — 12.3 |
| Punjab | 29.625 | 29.469 | —.156 | 102.5 | 99.5 | — 3.0 |
| Madras | 29.757 | 29.738 | —.019 | 95.6 | 89.8 | — 5.8 |
| Bombay | 29.778 | 29.739 | —.039 | 94.7 | 83.6 | — 11.1 |
| Berar and Central Provinces | 29.671 | 29.584 | —.087 | 106.2 | 86.1 | — 20.1 |
| Central India | 29.659 | 29.540 | —.119 | 104.7 | 86.7 | — 18.0 |
| Rajpootana | 29.670 | 29.519 | —.151 | 104.9 | 91.3 | — 13.6 |

| District. | Average monthly minimum temperature. | | | Diurnal range of temperature. | | Average monthly mean relative humidity. | | | Average proportion of clouded sky. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | May. | July. | Change. | May. | July. | May. | July. | Change. | May. | July. | Change. |
| Burmah | 77.0 | 75.5 | —1.5 | 15.8 | 9.7 | 75 | 89 | +14 | 5.8 | 8.4 | +2.6 |
| Bengal and Orissa | 77.3 | 78.7 | +1.4 | 16.3 | 9.8 | 75 | 83 | + 8 | 4.7 | 8.1 | +3.4 |
| Behar and Chuta-Nagpoor | 75.6 | 78.0 | +2.4 | 22.7 | 11.2 | 52 | 83 | +31 | 2.7 | 7.8 | +5.1 |
| Northwestern Provinces | 77.4 | 79.2 | +1.8 | 26.6 | 12.5 | 38 | 77 | +39 | 1.6 | 7.1 | +5.5 |
| Punjab | 73.3 | 80.1 | +6.8 | 29.2 | 19.4 | 39 | 60 | +21 | 2.1 | 3.9 | +1.8 |
| Madras | 76.2 | 73.9 | —2.3 | 19.4 | 15.9 | 64 | 71 | + 7 | 4.9 | 7.6 | +2.7 |
| Bombay | 76.2 | 73.4 | —2.8 | 18.5 | 10.2 | 62 | 83 | +21 | 3.3 | 8.3 | +5.0 |
| Berar and Central Provinces | 79.3 | 74.0 | —5.3 | 26.9 | 12.1 | 34 | 80 | +46 | 2.9 | 8.2 | +5.3 |
| Central India | 77.2 | 75.1 | —2.1 | 27.5 | 11.6 | 29 | 79 | +50 | 2.7 | 7.9 | +5.2 |
| Rajpootana | 77.2 | 77.1 | —0.1 | 27.7 | 14.2 | 36 | 74 | +38 | 1.7 | 7.3 | +5.6 |

The great heat in central Asia is often ascribed as an important factor in producing and maintaining the southwest monsoon circulation. This, I think, is an erroneous view to take. The whole of central Asia to the north of India is a large plateau from 10,000 to 15,000 feet above sea level. The pressure in that area at that elevation undoubtedly affects the pressure in India to some extent, but only indirectly. It does not give gradients in northern India as determined by the reduction of the pressure to sea level, and the direction of the winds in that area is due to other causes. The southwest lower atmospheric current probably (as has been shown by Blanford and others) does not extend to a greater height than 12,000 or 15,000 feet and hence is limited to the north and northwest by the Himalayas and Afghan mountains. Heavy rainfall in eastern Thibet in the monsoon months is sometimes adduced as a proof of the extension of the southwest monsoon across the Himalayas. There may be an inflow of air up the river valleys of Burmah and in the eastern Himalayas, where several of the rivers break through the mass of the Himalayas, but that the monsoon current should cross the large elevated mass of the Himalayas, with their great snow covering, and deposit so small a proportion of its aqueous vapor as to be able to precipitate large amounts in the heated table lands to the north,

even by forced ascent up the lower ranges to the north of the Himalayas, appears to be extremely improbable and to be opposed to theory.

The southwest monsoon circulation is hence an extension of the southeast trades into the Indian area and the Malay Peninsula which usually commences in the last week of May and is usually completed over nearly the whole of India in the third or fourth week of June. It continues in full vigor in July and August and begins to show signs of decreasing strength in September. It usually withdraws from upper India in the last week in September and from nearly the whole of the Arabian Sea in the month of November. Its retreat from northern India down the Bay of Bengal is a more complex phenomenon than its withdrawal from the Arabian Sea. This is in part due to the character of the pressure changes in central and southwestern Asia which accompany the retreat of the monsoon current from upper India, and in part to the geographical features of the Bay of Bengal. The current in retreating down the bay, recurves and discharges heavy rains on the Madras coast districts, thus tending to prolong its existence in the bay. It usually withdraws from the bay in the third or fourth week of December. Hence, during the whole of the period, from the beginning of June to the end of December, the southwest humid winds of the southwest monsoon circulation prevail over a part or the whole of the Indian land area and by far the greater part of the rainfall of India occurs during this period.

According to Blanford's estimate, the average annual rainfall of India is 40.6 inches, and of this at least 37 inches, or 90 per cent, fall during the southwest monsoon period, from May to December.

The interior of northern India is, previous to the establishment of the southwest monsoon, one of the hottest and driest areas in the world. Over the greater part of the Punjab, Sinde, Rajpootana, Central India, and Northwestern Provinces maximum temperatures in the shade of 110° and upward are of frequent occurrence, and occasionally temperatures of 120° to 124° are registered in the hottest parts of Sinde, the Punjab, and Rajpootana. Humidity frequently falls below 20° during the hotter part of the day, and humidities as low as 3.2° and 1° are occasionally recorded. Cultivation is, hence, almost entirely suspended during this period in the interior.

The conditions under which the humid monsoon current advances over and withdraws from the Indian area at once explain the broad features of the southwest monsoon rainfall. Southern India and the Deccan receive general and moderately heavy rainfall during the month of May and the first half of June, occasional showers during the next four months, and moderate to heavy rain from the beginning or middle of October to the end of the year. The latter burst is

heaviest in the Coromandel coast districts. Northern and Central India, on the other hand, obtain general and frequent rain in the interval from the middle of June to the end of September or middle of October. The distribution of this rainfall depends upon a variety of causes, fully stated in Mr. Blanford's monograph on the "Rainfall of India." The causes depending on the geographical features of the country and their relations to the rain-bearing current are the most important factors. The distribution of the rainfall varies largely from year to year, due to various causes, which may be defined as the special meteorological conditions of the period in the Indian monsoon area (and perhaps in the Indian Ocean).

The northeast monsoon in northern India comprises two periods, named from their temperature features, the cold weather and the hot weather. The cold weather includes the months of January and February. During that period shallow, but extensive, depressions and cyclonic storms pass across northern India from east to west and give light to moderate rain. The greater part of the snowfall of the western Himalayas and Afghan Highlands occurs during their existence. This precipitation is of great value for the wheat crop of northern India, and also for the supply of the rivers and canals of northern India during the succeeding hot weather. The rainfall of this period is not only small in amount in the plains, but extremely irregular in its occurrence from year to year, and its variations are, relatively to the normal, even greater than those of the southwest monsoon.

During the hot weather local storms are of frequent occurrence. In the drier parts of the country the storms are usually dust storms, accompanied with little or no rain. The only area to which these hot weather storms give frequent rain is Bengal and Assam. Thus, in east and north Bengal and Assam the average normal rainfall of the hot weather period from March to May exceeds 15 inches, and averages 42 inches in the districts of Cachar and Sylhet, where it is heaviest. It is mainly due to the forced ascent of the local sea winds by the hills of east Bengal and Assam.

The following statement shows the important periods of rainfall in each of the larger provinces of India:

*Character of rainfall.*

| Province or area. | Periods and character of rainfall. |
|---|---|
| Punjab | (1) Moderate rain in the cold weather (December to February).<br>(2) Moderate to heavy rain in southwest monsoon from July to October. |
| Sinde | (1) Light rain in cold weather (December to February).<br>(2) Occasional showers in July and August. |
| Rajpootana and Central India | (1) Light rain in cold weather.<br>(2) Moderate to heavy rain in southwest monsoon from June to September. |
| Northwestern Provinces and Behar | (1) Light to moderate rain in the cold weather.<br>(2) Moderate to heavy, frequent rain in the southwest monsoon from June to September or the middle of October. |

*Character of rainfall*—Continued.

| Province or area. | Periods and character of rainfall. |
|---|---|
| Bengal and Assam | (1) Heavy occasional rain in the hot weather months of March, April, and May. (2) Frequent and heavy rain throughout the southwest monsoon from June to the beginning of October, and occasional showers in October. |
| Burmah | Daily heavy rain in the coast districts from June to October and showers in November. Frequent moderate showers in central Burmah. |
| Bombay coast districts | Very heavy and almost daily rain from June to October. |
| Central Provinces, Berar and Hyderabad. | Frequent and moderate to heavy rain from June to September, and showers in October and November. |
| Bombay and Madras Deccan | Moderate rain at the beginning (June) and end of the monsoon (October and November), and occasional showers July to September. |
| Madras | More or less frequent showers from May to October, heaviest in the northern coast districts and least frequent and lightest in the southern districts of Tinnevelly and Madura. Frequent moderate to heavy rain from October to December, an amount as a rule decreasing rapidly with distance from Coromandel coast. |

The following table gives data showing the more important features of the distribution of the rainfall throughout India. In the first four figure columns are given the normal amounts for the four seasons into which the year is divided for meteorological purposes in India, and in the fifth and sixth columns, the normal rainfall in the northeast monsoon and southwest monsoon periods:

TABLE II.—*Showing the normal seasonal distribution of rainfall in India.*

| Division. | Cold weather period, January and February. | Hot weather period, March to May. | Southwest monsoon period, June to Oct. | Retreating southwest monsoon, Nov. and Dec. | Northeast monsoon, January to June. | Southwest monsoon, June to December. | Ratio of $c+d$ to $a+b$. |
|---|---|---|---|---|---|---|---|
| | *a* | *b* | *c* | *d* | $a+b$ | $c+d$ | |
| Burmah (lower) | 0.37 | 12.71 | 84.01 | 3.95 | 13.08 | 87.96 | 6.7 |
| Bengal and Orissa | 1.35 | 11.12 | 59.61 | 0.95 | 12.47 | 60.56 | 4.9 |
| Assam | 2.31 | 31.78 | 71.96 | 1.26 | 34.09 | 73.22 | 2.1 |
| Behar | 1.02 | 3.48 | 42.49 | 0.34 | 4.50 | 42.83 | 9.5 |
| Chuta-Nagpoor | 1.34 | 3.91 | 47.52 | 0.68 | 5.25 | 48.20 | 9.2 |
| Northwest Provinces and Oudh | 1.19 | 1.37 | 34.32 | 0.42 | 2.56 | 34.74 | 13.6 |
| Punjab | 1.87 | 2.22 | 14.98 | 0.54 | 4.09 | 15.52 | 3.8 |
| Bombay and Malabar coast districts (Madras) | 0.19 | 4.18 | 54.97 | 3.06 | 4.37 | 58.05 | 13.3 |
| Central Provinces and Berar | 0.72 | 1.54 | 43.65 | 0.89 | 2.26 | 44.54 | 19.7 |
| Bombay (north) | 0.32 | 0.41 | 24.67 | 0.18 | 0.73 | 24.85 | 34.0 |
| Rajpootana and Central India | 0.65 | 0.82 | 26.68 | 0.38 | 1.47 | 27.06 | 18.4 |
| Madras | 0.49 | 3.29 | 27.06 | 6.64 | 3.78 | 33.70 | 8.9 |

The preceding remarks have stated the chief features in the occurrence of rainfall in India. Mr. Blanford, in his "Rainfall of India," estimates the average rainfall of India and Burmah to be 42 inches. The variation, or as it may be more appropriately termed the range of rainfall, has wider limits than in any other part of the world. The region of least rainfall is upper Sinde, over a large portion of which the average annual rainfall in less than 5 inches.

The largest average rainfall not only in India but in the world is that of Cherra Punji, amounting to about 500 inches.

The range of variation of the rainfall from year to year is also very large and probably larger over a considerable portion of India than in any other country. Thus, at Kurrachi a total of 0.47 inch was received in 1872, and 28 inches in 1869. The largest and smallest amounts received during the past thirty-six years at Jacobabad are 12.05 inches and 0.72 inch, respectively.

India may be divided into three zones according to the average distribution of the rainfall.

1. The arid zone in which the annual average rainfall is less than 15 inches. In this area cultivation is wholly dependent on irrigation and, hence, independent of variations in the seasonal rainfall. It is, consequently, practically a non-famine area. This area includes Sinde, the southwest Punjab, and west Rajpootana.

2. The dry zone in which the average annual rainfall ranges between 15 and 35 inches. In this area the rainfall is sufficient, in the average of years, to maintain an agricultural population, but a prolonged deficiency usually leads to seasons of scarcity of greater or less intensity. This area includes the greater part of the Deccan, Mysore, south Madras, east Rajpootana, the central and south Punjab, and the western half of the Northwestern Provinces.

3. The moist zone in which the rainfall ranges from 35 inches to 200 inches in Arakan and Tenasserim, 300 inches in the west Ghats, and 500 inches in the Khasia Hills. In this area, which includes those portions of India not named in the preceding, the rainfall is, excepting under an extraordinary combination of circumstances, sufficient even in poor seasons to insure a fairly adequate food supply. Hence, this zone, like the first, is practically a non-famine area.

Mr. Blanford has established that in India the rainfall is most variable from year to year where it is smallest in amount, and is most regular and steady in amount where it is greatest. The range of variation is hence very large in the arid and dry zones and it is on account of the very great variability of the rainfall from year to year that the dry zone is peculiarly susceptible to famines.

The regions which are hence most liable to drought and to famine are those in which the rainfall is between 20 and 35 inches and includes:

1. The western and southern districts of the Northwestern Provinces and that portion of the Punjab south and east of the Sutlej.

2. Rajpootana (except the most western districts).

3. The Deccan districts of Bombay and Madras, Mysore, and the south and western districts of Hyderabad.

4. The Madras east coast districts and the southern districts of Madura, Tinnevelly, Coimbatore, Salem, and Trichinopoly.

5. The central districts of upper Burmah. These drought areas are shown in the subjoined map (Plate XII).

The following gives a brief statement of the chief food crops in different parts of India and the distribution of rainfall necessary to secure good crops:

1. Punjab, Rajpootana, Northwestern Provinces, Central India, Berar, and Central Provinces. The chief cold weather food crops are wheat, barley, pulses, which are sown at end of rains, and reaped in March and April. The chief rain food crops are millets, on high and unirrigated lands, and rice on low, moist, and irregular lands.

2. Bengal and lower Burmah. The chief food crop is rice, the main crop of which is reaped in December and January.

3. Deccan and southern India. The chief food crops in dry lands are millets, and in low irrigated lands, rice. Two crops of rice are obtained in some parts.

The favorable conditions necessary for abundant crops are as follows:

1. For cold weather crops of wheat, etc., a moderate burst of rain in October, in order that the ground may be plowed and the land may contain sufficient moisture to germinate the seed. Occasional light showers during the cold weather, more especially on the higher lands, in order to develop the crop fully.

2. Hot weather crops of rice. Heavy burst of rain is required in order to plant it out, frequent, moderate rain to provide a sufficient supply of water, and a burst of rain in the later stages to insure the growth of the ear. The last is most important to insure a full crop.

3. Hot weather crops of millets, etc., moderately heavy to heavy rain at the commencement to thoroughly saturate the soil and fit it for cultivation, and occasional moderate rain during the remainder of the season. Prolonged breaks exceeding three weeks or a month, more especially if they are accompanied by dry, hot winds, are very injurious to these crops, and if protracted, fatal.

Famines are the result of drought over large areas. The following are the chief causes which contribute to failure of the crops by drought and consequent famine:

1. Prolonged delay in the commencement of the rains, more especially of the southwest monsoon rains.

2. A prolonged break in the middle of the southwest monsoon rains.

3. Scanty rainfall during the greater part or the whole of the season.

4. Unusually early termination of the southwest monsoon rains. This is especially fatal in the case of rice crops on unirrigated land.

In northern India famine is usually due either to the failure of two crops in succession, as for example, the rain crop and the cold weather

crop (the *kharif* and the *rabi*, as they are usually named in India), or to the complete failure of one crop after a succession of poor or bad seasons.

In the Deccan they are usually due to the more or less complete failure of a southwest monsoon rainfall throughout, following one or more bad seasons.

In the rice-growing districts, on unirrigated lands, or lands not subject to inundation from rivers, the cause is usually abnormally early termination of the southwest monsoon rains.

The following table shows, in chronological order, the years in which the principal droughts since 1769 have occurred, and the province affected by consequent scarcity:

*Years of principal droughts.*

| Year. | Area of droughts. | Area of famine or scarcity. |
|---|---|---|
| 1769.. | Drought in Bengal. | |
| 1770.. | ........................ | Famine in Bengal. |
| 1782.. | Drought in Bombay and Madras. | |
| 1783.. | Drought in upper India........................ | Famine in Madras and scarcity in Bombay. |
| 1784.. | ........................ | Famine in upper India from the Karmanassa to the Sutlej. |
| 1791.. | Drought in Bombay, Hyderabad, and Madras. | |
| 1792.. | ........................ | Scarcity in north part of Madras. Intense famine in Hyderabad and southern Mahratta country. Severe famine in Deccan, Guzerat, and Marwar. |
| 1802.. | Drought in south Hyderabad and in Deccan. | |
| 1803.. | Drought in ceded province of Northwestern Provinces and in Central India. | Famine in Deccan and Hyderabad. |
| 1804.. | ........................ | Famine in Northwestern Provinces, and scarcity in Central India and Rajpootana. |
| 1806.. | Drought in central districts of Madras from Trichinopoly to Nellore. | |
| 1807.. | ........................ | Famine in central districts of Madras. |
| 1812.. | Drought in Guzerat, Kutch, and Kathiawar, and to some extent in Madras; also in Rajpootana and Central India. | |
| 1813.. | ........................ | Famine in Kutch and Kathiawar; intense in parts of Rajpootana. Scarcity in parts of Northwestern Provinces and of Madras. |
| 1823.. | Drought in Madras. | |
| 1824.. | Drought in Bombay........................ | Famine in Madras, chiefly in the north. |
| 1825.. | ........................ | Scarcity in Bombay, chiefly in Guzerat and the northern Deccan. |
| 1832.. | Drought in the northern districts of Madras, except Ganjam, in the south of Hyderabad and southern Mahratta districts of Bombay. | |
| 1833.. | Drought in north part of Bombay, in Rajpootana, and in parts of Punjab and Northwestern Provinces. | Famine in northern districts of Madras. Intense in Gantur. Scarcity in Hyderabad and southern Mahratta districts. |
| 1834.. | ........................ | Scarcity in north Deccan and Guzerat, in Rajpootana, the Hissar division of Punjab, and the trans-Jumna districts of Northwestern Provinces. |
| 1837.. | Drought in Northwestern Provinces, eastern states of Rajpootana, and southeast part of Punjab. | |
| 1838.. | Drought in Guzerat, Kutch, and Kathiawar.. | Intense famine in central Doab and trans-Jumna districts of Northwestern Provinces, and in Delhi and Hissar divisions of Punjab. |
| 1839.. | ........................ | Scarcity in Guzerat, Kutch, Kathiawar. |
| 1844.. | Scanty rainfall in Deccan. | |
| 1845.. | ........................ | Scarcity in Deccan. |
| 1853.. | Drought in ceded districts of Madras, in south Hyderabad, and Sholapur and Kuladgee districts of Bombay. | |
| 1854.. | ........................ | Famine in Bellary. Scarcity in adjoining parts of Madras, Hyderabad, and Bombay. |
| 1860.. | Drought in part of Northwestern Provinces and Punjab, and neighboring states of Rajpootana. | |

*Years of principal droughts*—Continued.

| Year. | Area of droughts. | Area of famine or scarcity. |
|---|---|---|
| 1861.. | ........................................... | Famine in upper Doab of Northwestern Provinces, in Delhi and Hissar divisions of Punjab, and in adjoining parts of Rajpootana. Scarcity in Kutch. |
| 1865.. | Drought in northern part of Madras, in south Hyderabad and north part of Mysore; in south Mahratta districts of Bombay, in Orissa and Behar, and all western Bengal. | |
| 1866.. | ........................................... | Famine in Ganjam and Bellary districts of Madras, in Orissa (intense) and in Behar. Scarcity in all adjacent parts of Madras, Mysore, Hyderabad, and Bombay, and in central and western Bengal. |
| 1868.. | Drought in Rajpootana, trans-Jumna districts of Northwestern Provinces, north and southeast districts of Central Provinces and in Punjab from Jumna to Indus. | |
| 1869.. | ........................................... | Famine in western Rajpootana (intense in trans-Jumna districts of Allahabad and Delhi), and in Hissar divisions of Punjab. Scarcity in adjacent parts of Northwestern Provinces and Punjab, in Guzerat, Kutch, and north Deccan, and in north and southeast districts of Central Provinces. |
| 1873.. | Drought in north Behar and a part of Northwestern Provinces and Oudh. | |
| 1874.. | ........................................... | Famine in Bahar and scarcity in the strip of Northwestern Provinces and Oudh adjacent. |
| 1876.. | Drought in all Madras and Deccan, Mysore, and south part of Hyderabad. | |
| 1877.. | Drought in Central Provinces, Northwestern Provinces, and Punjab. | Famine in Madras, Mysore, Bombay, and Hyderabad. |
| 1878.. | ........................................... | Famine in Northwestern Provinces and Cashmere. Scarcity in Punjab. |
| 1890.. | Drought in Madras ........................... | 1890-'91. Scarcity in central Madras, more especially the Salem, Coimbatore, Nellore, Bellary districts. |
| 1891.. | Drought in Rajpootana ........................ | 1891-'92. Severe scarcity in Rajpootana, most pronounced in Cymore and neighboring districts. |

The following is a summary of the preceding data collected by the Famine Commission and continued to the present date:

During the one hundred and twenty-two years, from 1770 to 1892, there have been 8 intense famines, 9 famines, and 6 severe scarcities. Omitting the latter, there have been 17 famines, occurring at average intervals of seven years. There have been 8 intense famines occurring at intervals varying from two to forty years, and averaging fifteen years.

Attempts have been made to discover a periodicity in the occurrence of famines corresponding to that of the sun-spot period, but they have not been very successful.

One of the most remarkable relations is the tendency for famine to occur in some part of northwestern India in the year succeeding that in which famine has prevailed in Madras. The following gives data:

| | |
|---|---|
| 1783. Famine in Madras. | 1784. Famine in upper India. |
| 1803. Famine in Deccan and Hyderabad. | 1804. Famine in the Northwestern Provinces. |
| 1833. Famine in north Madras. | 1834. Scarcity in the Northwestern Provinces, etc. |
| 1877. Famine in Madras. | 1878. Famine in Northwestern Provinces and Kashmir. |

This has happened in four well-marked cases, sufficient to show that there is some causal relation between the two events. The following gives an explanation based on three fairly well-established principles or observed relations:

1. Opposition between the meteorological conditions of extra-tropical and tropical India, shown more especially in the abnormal features, or variations from the normal condition.

2. Tendency for light monsoon in northern India to be followed by light cold weather rains, and for heavy southwest monsoon rains, to be followed by heavier rainfall than usual in the succeeding cold weather.

3. Tendency for light cold weather to be followed by heavy southwest monsoon rains, and *vice versa*.

It may be premised that these are in accordance with theoretical considerations concerning meteorological changes in the upper and lower air strata over India, accompanying the large seasonal air movements over India.

The causes of famines in Madras are as yet imperfectly investigated, but they appear to be due to persistent excess of pressure in the Deccan and deficient pressure in northern India. In such cases the rainfall in northern India is generally heavier than usual, while that of the Deccan and southern India is more or less largely in defect.

The heavy southwest monsoon rains in northern India are then followed, according to principle 2, by more abundant rain in the following cold weather in northern India, and by excessive snow in the hills. This, by 3, tends to be followed by very deficient rainfall and by a retarded monsoon in northern India, and hence also, by 2, by deficient rainfall in the ensuing cold weather, and if this deficient rainfall or drought during these two periods is sufficiently severe, famine ensues.

The chances that drought in southern India (Madras and the Deccan) will be followed by more or less severe drought in the next year over some part of northern India are about five to two.

The following gives a very brief summary of the last eight large famines in India. The areas affected by these famines are shown in the charts (Plate XIII):

### MADRAS FAMINE OF 1832–'33.

*Area affected.*—Central Madras, especially the Guntoor district. (Fig. 1.)

*Cause.*—Partial failure of the ordinary southwest monsoon rains, followed by complete failure of retreating southwest monsoon rains in 1832 over the area affected.

*Period.*—From failure of crops in 1832 to harvest of 1833, during which year the rains were favorable.

*Loss to state.*—Estimated at 52 lakhs (£520,000).

*Loss of life.*—Not known, but large. It is estimated that in the Guntoor district,

where the loss was greatest and famine most fatal, 150,000 to 200,000 perished out of a total population of 500,000.

### FAMINE IN UPPER INDIA, 1837.

*Area affected.*—Included the Doab (between Ganges and Jumna), the trans-Jumna districts of the Northwestern Provinces, and the adjacent districts of Rajpootana. The total area affected was 96,000 square miles, with a population of 28,000,000. (Fig. 2.)

*Cause.*—No information, except general statement that rains failed to such an extent that not only kharif failed, but it was not possible to sow the rabi crops. Hence, it is almost certain it was due to the rains and cold weather crops both failing.

*Period.*—From cold weather of 1837 to end of rains of 1838. The latter were late but were, on the whole, favorable. Hence, it lasted nearly a year.

*Loss to state.*—Estimated at 11,500,000 rupees, or £1,150,000.

*Loss of life.*—It was estimated at 800,000, but this is probably below the mark.

### MADRAS FAMINE OF 1854.

*Area affected.*—The area which suffered was of comparatively small extent and included the Bellary district and the adjacent districts of Madras and the Hyderabad state. (Fig. 3.)

*Cause.*—The rains of 1852 were exceptionally heavy and crops were, hence, unsatisfactory. The ordinary monsoon rains of 1853 were light and the retreating monsoon rains failed almost entirely. The famine was, hence, due to a partial failure of one complete season following a previous bad season.

*Period.*—The famine lasted from the end of 1853 to November, 1854. The rains of 1854 were favorable and the famine was terminated by the harvest of that year.

*Loss of cattle.*—About one-third of the cattle are estimated to have died.

*Loss to state.*—4,250,000 rupees, or £425,000.

*Loss of life.*—No available estimate, but it is believed to have been considerable.

### FAMINE OF 1860–'61 IN THE NORTHWESTERN PROVINCES AND PUNJAB.

The following gives data for four stations (with approximate normal rainfall data) from June, 1860, to March, 1861:

| Month and year. | Actual rainfall. | | | | Approximate normal rainfall of month in Northwestern Provinces. |
|---|---|---|---|---|---|
| | Multan. | Aligarh. | Bulandshahr. | Meerut. | |
| June, 1860 | 0.0 | 0.4 | 0.0 | 0.0 | 3.0 |
| July, 1860 | 10.6 | 6.0 | 0.7 | 1.4 | 9.0 |
| August, 1860 | 0.9 | 7.5 | 0.4 | 6.2 | 7.0 |
| September, 1860 | 0.1 | 0.2 | 0.0 | 1.3 | 4.0 |
| October, 1860 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 |
| November, 1860 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| December, 1860 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 |
| January, 1861 | 0.1 | 0.6 | 0.5 | 0.1 | 0.5 |
| February, 1861 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 |
| March, 1861 | 0.0 | 0.0 | 0.0 | 0.6 | 0.3 |
| Total (in inches) | 11.7 | 14.7 | 1.6 | 9.6 | 25.0 |

*Area affected.*—The area in which the famine was severe included Rohilkhand, the Doab, and trans-Jumna district of the Northwestern Provinces, and the portion of the

Punjab between the Sutlej and Jumna. The famine was very severe between Delhi and Agra on both sides of the Jumna. The total population affected by it numbered 13,000,000. (Fig. 4.)

*Cause.*—The seasons of 1858 and 1859 were unfavorable. In 1860 the monsoon rains failed almost entirely. They began late in the middle of July. There was a long break in August, and they ceased much earlier than usual. The kharif crops failed, and it was not possible to sow the rabi crops on account of the dryness of the land in October. The cold weather rains also failed.

*Period.*—The famine lasted from January, 1861, to September, 1861. The rains were abundant in 1861 and the harvest satisfactory.

*Loss of cattle.*—600,000 are estimated to have perished during the famine.

*Loss of life.*—No satisfactory estimate can be given in the absence of data, but the loss almost certainly exceeded 500,000.

### ORISSA FAMINE OF 1865–'66.

*Area affected.*—The whole of the east coast of India from Madras to Orissa and extending to a considerable distance inland, and also Chuta-Nagpoor and south Behar. It was most severe in Ganjam and Orissa. It was, hence, most severe in a portion of the moist zone. (Fig. 5.)

*Cause.*—The chief cause was the very early termination of the ordinary southwest monsoon rains and the failure of the retreating southwest monsoon rains in 1865. The rains were very irregular up to August, 1865, and ceased entirely in Orissa and Ganjam in the beginning of September. The great rice crop of the season was, hence, an almost total failure. The famine was aggravated by the want of communication.

*Period.*—The famine lasted in full severity from November, 1865, to November, 1866, when the rice crop of that year (on the whole not a favorable one in consequence of extraordinary rains and serious inundations) was harvested. It was, however, not till the harvest of 1867 that the effects of the famine passed away from Orissa.

*Loss to state.*—In various ways was estimated at nearly £1,500,000 in Bengal and Orissa alone.

*Loss of life.*—In Orissa alone the loss of life was estimated at 1,000,000 out of a total population of 3,000,000.

### FAMINE OF NORTHWESTERN INDIA IN 1868–'69.

The following gives the rainfall at three stations, for which data are available, for the period:

| Month and year. | Actual rainfall. | | | Approximate normal rainfall of month in central Rajpootana. |
|---|---|---|---|---|
| | Jeypoor. | Beawar. | Ajmir. | |
| June, 1868 | 0.5 | 0.4 | 1.0 | 3.0 |
| July, 1868 | 7.8 | 3.8 | 6.4 | 8.0 |
| August, 1868 | 0.0 | 0.8 | 0.8 | 6.5 |
| September, 1868 | 1.1 | 0.0 | 0.0 | 3.0 |
| October, 1868 | 0.0 | 0.0 | 0.0 | 0.3 |
| November, 1868 | 0.0 | 0.0 | 0.0 | 0.1 |
| December, 1868 | 0.0 | 0.0 | 0.0 | 0.3 |
| January, 1869 | 0.2 | 0.5 | 0.4 | 0.2 |
| February, 1869 | 0.0 | 0.3 | 0.4 | 0.3 |
| Total (in inches) | 9.6 | 5.8 | 9.0 | 21.7 |

*Area affected.*—This famine was most severe in Rajpootana, more especially the western and central districts. It was also felt in the adjacent districts of the Punjab, Northwestern Provinces, Central India, and the Central Provinces. (Fig. 6.)

*Cause.*—The rains of 1868 commenced late and ceased very early. In part of Rajpootana the only rain of importance fell in July. The ensuing cold weather or rabi crop was also very scanty.

*Period.*—The period of intense famine lasted from the month of October, 1868, until March, 1870. The rains of 1869 were very heavy, but a severe epidemic of fever in Rajpootana enfeebled the people to such an extent that they were unable to reap and house the scanty harvest which had been spared by a plague of locusts. The famine was only terminated by a favorable cold weather harvest in March, 1870. The famine was, hence, unusually prolonged in consequence of the treble visitation of drought, fever, and locusts.

*Loss of life.*—According to estimates made at the time, probably 1,500,000.

*Loss of cattle.*—Hardly a tenth of the cattle survived in Rajpootana, and it is estimated that nearly 3,000,000 died.

*Loss to state.*—The direct loss probably exceeded 70 lakhs, or £700,000, and the indirect loss in the shape of revenue can not be estimated.

### BEHAR FAMINE OF 1873–'74.

The following rainfall data for two stations in the center of the famine area show the character of the rainfall:

| Month and year. | Actual rainfall. | | Approximate normal rainfall of month in north Behar. |
|---|---|---|---|
| | Durbhunga. | Chupra. | |
| | *Inches.* | *Inches.* | *Inches.* |
| June, 1873 | 3.9 | 3.4 | 7.0 |
| July, 1873 | 7.0 | 15.6 | 11.0 |
| August, 1873 | 7.2 | 10.8 | 10.0 |
| September, 1873 | 2.8 | 1.1 | 8.5 |
| October, 1873 | 0.0 | 0.0 | 3.0 |
| November, 1873 | 0.0 | 0.0 | 0.2 |
| December, 1873 | 0.0 | 0.0 | 0.1 |
| Total | 20.9 | 39.9 | 39.8 |

*Area affected.*—The area affected included the whole of Behar and the adjacent districts of North Bengal and the Northwestern Provinces. It was most intense in the northern districts of Behar, more especially Durbungah, Saran, Champaran, Bhagalpur, Purneah, Dinagepoor, Rungpoor, and Bogra. (Fig. 7.)

*Causes.*—The southwest monsoon rains of 1873 ceased unusually early in the beginning of September, at least six weeks earlier than usual. The rains, hence, failed almost entirely in September and October, when rain is most essential for the growth of the great winter rice crop. The cold weather rains were below the normal and the winter crop deficient to some extent.

*Period.*—Lasted from January, 1873, to September or October, 1874. The famine was terminated by favorable rains and good crops in 1874, and an abundant rice harvest was secured in December, 1874.

*Loss of life.*—Very small in consequence of the special efforts made to relieve distress in the earlier stages.

*Loss to the state.*—The cost of the actual relief to the distressed people in the famine area in Behar was £6,000,000. The indirect loss in the shape of revenue, etc., was probably smaller than in preceding large famines.

MADRAS FAMINE OF 1876–'77.

The following table, giving rainfall data for six stations, shows the character of the rainfall during the period:

| Month. | Actual rainfall. | | | | | | Approximate normal rainfall of month in central Deccan. |
|---|---|---|---|---|---|---|---|
| | Karnool. | Gooty. | Cuddapah. | Dharwar. | Kalghatgi. | Naldroog. | |
| | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* |
| June, 1876 | 3.73 | 1.25 | 0.80 | 2.06 | 2.80 | 5.13 | 3.0 |
| July, 1876 | 1.26 | 1.20 | 0.75 | 8.92 | 10.01 | 2.12 | 3.5 |
| August, 1876 | 1.50 | 1.07 | 6.25 | 1.48 | 1.66 | 3.61 | 5.0 |
| September, 1876 | 0.11 | 2.00 | 1.10 | 1.84 | 1.60 | 2.37 | 6.0 |
| October, 1876 | 0.00 | 0.35 | 0.35 | 1.62 | 0.57 | 0.00 | 5.0 |
| November, 1876 | 0.55 | 0.70 | 0.00 | 0.29 | 0.00 | 0.00 | 3.5 |
| December, 1876 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.1 |
| Total | 7.15 | 6.57 | 9.25 | 16.21 | 16.64 | 13.23 | 26.1 |

*Area affected.*—Nearly the whole of the Bombay Deccan, the southern half of the Hyderabad State, Mysore, the Madras Deccan. (Fig. 8.)

*Cause.*—The rainfall of the first three months of the southwest monsoon, 1876 (June to August), was scanty and irregular. The rains ceased at the end of August, upward of two months before the normal date, that of the retreating southwest monsoon failed almost entirely.

*Period.*—In Madras and Mysore the famine lasted from October, 1875, to December, 1877. The retreating southwest monsoon rains of 1877 were unusually abundant and the rains of 1878 were favorable. The previous monsoon rains (1875) had partially failed, and hence in that area the famine was due to a drought lasting through two monsoons.

*Cost of relief.*—Bombay, 11,400,000 rupees; Hyderabad, 4,000,000 rupees; Madras, 68,000,000 rupees; Mysore, .........(?).

*Loss of life.*—Comparatively small.

SEVERE SCARCITY IN THE NORTHWESTERN PROVINCES IN 1877–'78.

The following gives rainfall data for six stations in the Northwestern Provinces in the area of greatest drought:

| Month. | Actual rainfall. | | | | | | Approximate normal rainfall of Northwestern Provinces, central. |
|---|---|---|---|---|---|---|---|
| | Bareilly. | Etah. | Muttra. | Etawah. | Agra. | Jhansi. | |
| | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* |
| June, 1877 | 2.6 | 1.6 | 0.3 | 0.0 | 0.4 | 1.7 | 3.0 |
| July, 1877 | 3.7 | 2.7 | 0.5 | 0.5 | 1.6 | 0.5 | 9.0 |
| August, 1877 | 3.1 | 0.2 | 0.0 | 0.4 | 0.6 | 2.3 | 8.0 |
| September, 1877 | 0.0 | 0.2 | 0.0 | 0.2 | 0.1 | 5.4 | 5.0 |
| October, 1877 | 6.6 | 4.9 | 6.3 | 5.0 | 3.6 | 2.3 | 1.0 |
| Total | 16.0 | 9.6 | 7.1 | 6.1 | 6.3 | 12.2 | 26.0 |

*Area affected.*—The area affected by the drought included nearly the whole of the Northwestern Provinces, Rajpootana, and the southeast Punjab. (Fig. 9.)

*Causes.*—The almost total failure of the southwest monsoon rains of 1877. Fortunately, a heavy downpour in October, 1877, enabled the rabi crops to be sown and good

Plate

cold weather rains gave fair spring crops. In consequence of the failure of the rains not extending to the cold weather as well as the monsoon rains the drought was followed by scarcity but not by famine.

*Period.*—From the end of the southwest monsoon rain period of 1877 (September and October) until the month of October, 1878. The rains of 1878 were not very favorable, but they gave a fair crop which was sufficient to close the scarcity.

# SECTION VI.

# ATMOSPHERIC ELECTRICITY AND TERRESTRIAL MAGNETISM.

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## 1.—MAGNETIC SURVEY OF NORTH AMERICA.

Prof. CHARLES A. SCHOTT.

At the time of the eventful rediscovery of North America, terrestrial magnetism, as a distinct science, had no existence; yet directly connected with this event was the capital discovery of two positions in the North Atlantic where the compass needle pointed due north, thus defining a portion of an agonic line and enlarging our ideas as to the geographical distribution of magnetism. At that time it was known to mariners that in western Europe and contiguous seas the magnetic needle pointed slightly to the east of north, and it was the general belief that the direction at that place was permanent.

The discoverers of places of no declination were Columbus and Sebastian Cabot. The former noticed on September 13, 1492, when in about latitude 28° 21′ north and longitude 29° 16′ west of Greenwich, that the needle had swayed to the opposite side of the true meridian, and that it remained westerly to the end of his voyage of discovery;[1] the latter a few years later, about June, 1497, when in a higher latitude (above 40°) and 110 miles west of the island of Flores (Azores), entered a region of west declination.[2] From this date to the present time west declination prevailed over Newfoundland and Nova Scotia and on the immediate coast, probably as far south as Virginia.

With the compasses then in vogue seamen probably did not care to read them closer than one-half point, or at the most one-fourth point, and the sun's azimuth when in the horizon was found by solar tables or astronomical calendars such as were published by Regiomontanus and Behaim. For the sixteenth century we have on record but a single station, on the coast of New Albion (now California), by Sir Francis Drake. The seventeenth century, however, opened more auspiciously, and contributions to our knowledge of the declination at these early dates were made by Hudson on his third voyage (1609) when skirting the Atlantic coast between Maine and North Carolina;

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[1] Appendixes 18 and 19, U. S. Coast and Geodetic Survey Report for 1880.

[2] U. S. Coast and Geodetic Survey Bulletin No. 6, May, 1888.

by Champlain (1604–'12) when coasting between Nova Scotia and Cape Cod; by W. Baffin, Upper Baffin Bay, in 1616. The great nautical work published at Florence by the Duke of Northumberland in 1646–'47, under the title *Del Arcano del Mare*, contains on its charts a great number of variations of the compass, sufficient to delineate isogonic curves[1] extending from the Pacific coast of the United States over Mexico, the Gulf, and up the Atlantic coast to Newfoundland. The epoch is estimated at 1620. A recent work by Dr. W. Van Bemmelen,[2] who has collected early observations of the declination and added newly discovered records from Dutch navigators, gives as the results of his researches six new isogonic charts. The two earliest of these, for the years 1540 and 1580, are more or less conjectural; the former just touches Greenland, the latter includes about the same region as that covered by the *Arcano del Mare*. His next chart for the epoch 1610 is more complete and includes all of North America east of longitude 80° west from Greenwich. This and the one following it for 1640 are in good accord with the isogonic lines constructed from the Arcano. His remaining charts, for the years 1665 and 1680, greatly assist in tracing out the secular motion of the American agonic line.[3]

According to the best information we now possess this agonic curve, when it first became known, touched the northern border of South America and followed the trend of Central America, and thence turned to the northeastward. In the meantime the first theoretical conceptions respecting terrestrial magnetism had become diffused through the publication, in 1600, of Gilbert's epoch-making work, *De Magnete*,[4] in which the earth is conceived to be itself a great magnet.

During the eighteenth century the observations of the declination became quite numerous, and in its last quarter a number of inclinations were recorded, the earliest being in 1775 on Hudson Bay, the next in 1778 in Nootka Sound, and in the east at Cambridge in 1782, although the dip had been discovered in 1544 and had become well known by Norman's rediscovery of it in 1576. Concurrently with the dip we have the first records of relative intensity of the magnetic force. Humboldt's observations (1798–1803) are the first of the kind in America. Our knowledge of the secular variation of the dip and intensity is still very limited, owing to the scarcity of data, the latest and most detailed charts of isoclinic and isodynamic curves being those by Lefroy in Canada and the British Possessions[5] from ob-

[1] *See* U. S. Coast and Geodetic Survey Bulletin No. 5, May, 1888.

[2] *De Isogonen in de XVIde en XVIIde Eeuw.*, Utrecht, 1893.

[3] *See* U. S. Coast and Geodetic Survey Bulletin No. 6, Washington, May, 1888.

[4] William Gilbert, of Colchester, "On the Loadstone and Magnetic Bodies, and on the Great Magnet, the Earth," etc.; translated by P. F. Mottelay, New York, 1893.

[5] Diary of the magnetic survey of a portion of the Dominion of Canada, etc., executed in the years 1842–'44. Gen. Sir J. H. Lefroy, London, 1883.

servations in the years 1842–'44, and those by the U. S. Coast and Geodetic Survey[1] collected from all available sources and reduced to the epoch 1885. This last publication also contains the latest information respecting the secular variation of the dip and intensity. While the results from explorations on land are yet meager, it is otherwise with those at sea, due in great part to the spirit of maritime explorations, which has continued to our own time. With respect to North America, we may mention the names of Bering[2] (1727–'29), Cook (1768–'80), La Perouse (1786), Spanish navigators (1774–'90),[3] Malaspina (1791), and Vancouver (1790–'95); and in the earlier part of the present century, Kotzebue (1815–'24), James and John Ross (1818), Parry (1820–'25), Franklin (1825), Beechey (1826–'28), Lütke (1827–'29), Erman (1828–'30), Du Petit Thouars (1837), Belcher (1837–'39), Wilkes (1841), Bayfield (1834–'53), Kellett (1849–'50), Maguire (1852–'54), and many other explorers.

Much information will be found in the great collection of magnetic results by Sir Edw. Sabine, covering the years 1840–'45, in vols. 162 and 165 of the Philosophical Transactions of the Royal Society,[4] and with respect to the United States, the U. S. Coast and Geodetic Survey Office has on record a large collection of magnetic data from the earliest to the present time. The later explorations of the Arctic regions of the Western Hemisphere yielded a great number of observations, nearly all of which have been discussed; among them are those of Dr. Kane (1853–'55), Dr. Hayes (1860–'61), Hall (1871), Nares and Markham (1875–'76), Greely (1881–'84).

Of land expeditions that of Lieut. Lefroy, in Canada and the Hudson Bay Company's territory, was perhaps the most extensive as yet undertaken on this continent. Many observations were made by Thos. Simpson and Lieut. Younghusband in the British Possesions of North America.

In the United States we have to mention the expedition of Maj. Long, U. S. A. (1819), the exploration tours of Prof. Nicollet (1832–'36), the extensive magnetic surveys of Dr. Locke (1838–'43), and Prof. Loomis (1838–'41); to the latter observer we are indebted for the first general collection of magnetic results, published by him in Silliman's Journal.[5] The magnetic survey by Karl Friesach (1856–'57) extended over part of the United States.

The observations made by army officers in charge of the geographical surveys west of the one hundredth meridian are very numerous, as are also the observations due to the U. S. Lake Survey, to the U. S.

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[1] U. S. Coast and Geodetic Survey Report for 1885, Appendix No. 6.

[2] U. S. Coast and Geodetic Survey Bulletin No. 20, December, 1890.

[3] U. S. Coast and Geodetic Survey Report for 1885, Appendix No. 7.

[4] Vol. 162, pt. 2, 1872, and vol. 165, pt. 1, 1875.

[5] Amer. Jour. Sci. and Arts. Vol. xxxiv, 1838, and Vol. xxxix, 1840.

Coast and Geodetic Survey, and to the surveys of the public lands; further we have results in connection with the marking of our international boundaries as well as of interstate boundaries, and there are the publications of state surveys in charge of geologists, as of New York (Regents' reports), of Pennsylvania, and of New Jersey.[1] The State of Missouri was surveyed through private enterprise[2] during 1878–'82; this survey is most complete and comprises declinations, dips, and intensities.

The magnetic surveys under the direction of the National Academy of Sciences, with the aid of the Bache fund, were carried on during 1871–'76,[3] and were published in 1882. Magnetic data are so scattered among a great variety of publications that anything like a complete collection is impossible.

Turning our attention to the differential measures, we find a number of magnetic observatories established since 1840, *i. e.*, about the time the British colonial magnetic observatories were established, and of which Toronto was one. They are as follows:

1. Philadelphia, Pa., 1840–'45. Dr. Bache, at Girard College; series published and discussed (*see* Coast and Geodetic Survey Reports for 1859, 1860, 1862, and 1863).

2. Toronto, Can., 1840–'93. Capt. Riddell, Lieut. Younghusband, Prof. Kingston, Prof. Carpmael. Gen. Sabine published three quarto volumes of the earlier years, and there is a small volume of abstracts and results printed at Toronto, with the date of 1875.

3. Sitka, Alaska, 1842–'64. Syrianow (?), on Japonski Island. Only declination differences were observed. Records published by the Central Physical Observatory of Russia.

4. Key West, Fla., 1860–'66. Established by the U. S. Coast Survey. W. P. Trowbridge and other observers. For description, see report for 1860, and for partial discussion of results, report for 1874.

5. Madison, Wis., 1878–'81. Established by the U. S. Coast Survey. No publication as yet.

6. Mexico, Mex., 1879–'93. Observatorio Central. V. Reyes, M. Barcena.

7. Los Angeles, Cal., 1882–'89. Established by the U. S. Coast and Geodetic Survey. M. Baker, C. Terry, and R. E. Halter, observers. For reduction and results, in four parts, see Annual Reports for 1891–'92. This is the most complete discussion of results as yet issued by the Survey.

8. Habana, Cuba, 1863–'93. Real Colegio de Belen. B. Viñes, S. J., in charge. The observations are published quarterly.

[1] Report of Prof. G. H. Cook, Trenton, 1888. A very complete survey with respect to magnetic declination.

[2] By Prof. F. E. Nipher of Washington University, St. Louis.

[3] U. S. Coast and Geodetic Survey Report for 1882, Appendix No. 14.

9. Washington, D. C., 1888–'93. U. S. Naval Observatory (old site). Publication by the U. S. Navy Department.

10. San Antonio, Tex., 1890–'93. Established by the U. S. Coast and Geodetic Survey. R. E. Halter and L. G. Schultz, observers. Removed to Hillside Ranch, near San Antonio, on account of disturbances by electric road, September, 1892. No publication as yet.

In connection with the International Polar Research (1882–'83), several observing stations were established in North America. These were, by the United States: Fort Conger, Grinnell Land, the northernmost of all stations, Lieut. Greely in charge; Uglaamie, Point Barrow, Alaska, Lieut. Ray in charge. By Denmark: Godthaab, in Greenland. By Germany: Kingua-Fjord, Cumberland Gulf. By Great Britain: Fort Rae, British Possessions. These several expeditions have published their observations. It can not be said, however, that these records have been fully utilized, as regards results, and much more may be expected, particularly from intercomparisons of the data furnished by all stations surrounding the northern magnetic pole. The question of a relocation[1] of this pole after a lapse of more than half a century has been agitated for some years,[2] but its importance for the general theory of terrestrial magnetism appears to have been overlooked during the international polar research. At present no positive answer can be given how far it may be said that this pole holds an invariable position, or whether it is subject to secular change, and if the latter, where it may now be found, and what are the laws of its motion. The distribution of the total intensity, when near its maximum value, in British America, to the westward and northward of Hudson Bay, is at present quite obscure, as this region appears to be irregularly broken up into several areas of very nearly equal maximum values.

The latest numerical application of Gauss' theory of terrestrial magnetism, by Drs. J. Neumayer and Petersen, for the epoch 1885, proved in general quite satisfactory,[3] yet it seems clear that in order to produce the best accord between computation and observation, even if the theory is limited to terms of the fourth order, it is requisite that the distribution of the data over the earth's surface be fairly regular, that no locally disturbed values be admitted among the data, and that we possess an adequate knowledge of the secular change for all three elements in order to reduce all the data to a certain epoch.

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[1] More than a single dash toward the pole is required; in fact, nothing short of a magnetic survey of the surrounding region will satisfy.

[2] For compendious information on this subject, see various papers published by the American Geographical Society of New York; Bulletin of the Society, Vol. XXIV, No. 2, of June 30, 1892.

[3] Berghaus' *Physikalischer Atlas*, 1892, Part IV. Preface to *Atlas des Erdmagnetismus*.

## 2.—MAGNETIC SURVEY OF EUROPE AND ASIA.

Gen. ALEXIS DE TILLO.

If we take the "Contributions to Terrestrial Magnetism," by Gen. Sir Edward Sabine, No. XIII, No. XIV, and No. XV, read before the Royal Society of London, respectively, on June 20, 1872, June 18, 1874, and June 15, 1876, and if we consider the tables, or zones, and the beautiful charts attached to those contributions, we are able to obtain a precise idea of the state in which the magnetic investigations of Europe and Asia were till the years surrounding the epoch of 1842.

The communications of Sabine comprehend the co-operative labors of many European and American contributors, acting for the most part independently of each other, within the limits of about twenty years preceding and twenty years following the mean epoch. There are nine charts in Sabine's work that we must use for our purpose; three for the north polar regions of the globe, three for the zones between the parallel of 40° north and the equator, and three for the zones between the equator and the parallel of 40° south. For each region one of the three charts is devoted to declination, another to inclination, and the third to total intensity, expressed in British units. It must be said that the charts of Sabine have a great value for the reason that they contain not only the magnetic isolines, but also the precise indication of the observed elements reduced to the common epoch of 1842.

In broad lines it is to be seen that much has been done, but the greater part of Asia is still without magnetic determinations. Let us throw a glance upon those countries which possess magnetic surveys, and begin from the western shores of Europe.

### EUROPE.

A magnetic survey of the British Isles for the epoch January 1, 1886, by A. W. Rücker and T. E. Thorpe was published by the Royal Society of London in the year 1890. Two magnetic surveys of the British Isles had been made previous to that, of which an account is given in this paper. The observations for these were taken between the years 1834–'38 and 1857–'62, and the results were reduced to the epoch 1842–'45, by E. Sabine, in a paper published in the Philosophical Transactions for 1870. Because the earlier surveys left much to be desired with regard to the distribution of the stations and the number of the declination observations, and in order that the secular changes might be redetermined, a complete new magnetic survey of the British Isles was undertaken in the course of the five years 1884–'88. The average distance apart in normal districts is about 30

miles, and the last survey is based on observations at about 250 different places.

The great work of Rücker and Thorpe is so fundamental that it is to be recommended for study to every serious magnetician. On the one hand there are given terrestrial isomagnetic lines in which all distortions due to local magnetism are neglected; on the other hand the true isomagnetic lines are represented which show every disturbance, local and regional. The most interesting part of the investigation consists in the relation between the magnetic and the geological constitution of the magnetic districts of the British Isles.

### FRANCE.

A new systematic magnetic survey of France has been made and published by M. Th. Moureaux (*Détermination des éléments magnétiques en France*, Paris, 1886). The first magnetic survey of this country is due to Lamont, who determined the elements of 44 stations in the years 1856 and 1857, and constructed magnetic charts in his work, *Untersuchungen über die Richtung und Stärke des Erdmagnetismus an verschiedenen Punkten des südoestlichen Europa*, Munich, 1858. A second survey was made by R. P. Perėy at 33 stations in the years 1868–'69, and there exist other observations, but the work of M. Th. Moureaux is the most complete, based on 79 stations, principally of the years 1884 and 1885. The work is accompanied by charts reduced to the epoch January 1, 1885. The local disturbances have been studied recently by Mascart and Moureaux in the *Comptes Rendus* of the French Academy, 1870.

### GERMANY.

Germany possesses a great number of magnetical determinations. Lamont, the great savant of Munich, himself made many series of voyages in all countries of west Europe, and observed the magnetic elements of more than 400 places during the years 1844, 1849–'50, 1852–'58, 1860. A detailed account of his work is to be found in the following publications: *Magnetische Ortsbestimmungen in Bayern*, I, 1854, II, 1856. *Magnetische Karten von Deutschland und Bayern*, München, 1854. *Untersuchung über die Richtung und Stärke des Erdmagnetismus in Südwestlichen Europa*, München, 1858, mit 6 Karten der magnetischen Linien. *Untersuchungen über die Richtung und Stärke des Erdmagnetismus in Nord Deutschland, Belgien, Holland, Dänemark*, München, 1859, mit 6 Karten. IV. *Supplement Band der Annalen der Münchener Sternwarte.*

The present director of the Marine Observatory at Hamburg, Dr. G. Neumayer, considers that a new systematic survey of Germany must be made, and investigations in different parts of this empire are partly executed by Prof. Neumayer himself, and by K. Schück,

Stamme, Eschenhagen, Schaper, H. Fritsche, O. Meyer, but a full inquiry is still in expectation.

### AUSTRO-HUNGARY.

The magnetic conditions of Austria and Hungary have been during many years studied by K. Kreil, professor at Prague. The corresponding principal publications are entitled as follows: *Magnetische und geographische Ortsbestimmungen in Böhmen* (1843–'45); *Magnetische und geographische Ortsbestimmungen im Oesterreichischen Kaiserstaate* (1846–'51); *Ueber den Einfluss der Alpen auf die Aenderungen der erdmagnetischen Kraft; Magnetische und geographische Ortsbestimmungen an den Küsten der adriatischen Golfs im Jahre* 1854; *Magnetische und geographische Ortsbestimmungen in südöstlichen Europa und einigen Küstenquarten Asiens* (*Denkschriften der Wiener Akademie*). For Hungary we must consider also the determinations in the years 1864–'81 executed by G. Schenzl at 126 stations. The results are to be found in Carl's *Repetorium der Physik*, Bd. XIII, and the complete work has been published by the Hungarian Society of Sciences.

Before proceeding to the eastern part of Europe, I shall say only a few words of the other secondary states of western Europe. Spain and Portugal, Belgium, Holland, Switzerland, and Denmark are included in the magnetical charts of Lamont. A part of Italy and of the Balkan states has been studied in that direction by Kriel. Norway and Sweden were the center of magnetic intelligence during the period of A. Hansteen, who acted at Christiania. New systematic surveys are under way in Italy by C. Christoni and in Sweden by Carlheim-Gyllenskjöld.

### RUSSIA.

The Russian Empire forms the eastern half of Europe and the northern part of Asia. There exists a valuable number of determinations of the magnetic elements by Hansteen and Due, Kuppfer, Kämtz, Wild, and Rykatschew; but it was the great energy of F. Smirnow who visited all parts of Russia in Europe and completed, in the years 1871–'78, a beautiful survey, and on the base of his observations I constructed magnetic charts for all the elements for the epoch 1880, considering also the previous materials, so that the sum of the stations was 600 and more.

A complete description is given in my works, *Ueber die geographische Vertheilung und säkulare Aenderung der Deklination und Inklination im Europaischen Russland*, mit 4 Karten, *Repertorium für Meteorologie*, Bd. VIII, No. 2 (1881); *Ueber die geographische Vertheilung und säkulare Aenderung der erdmagnetischen Kraft im Europaischen Russland*, mit Karten, *Rep. für Met.*, Bd. IX, No. 5 (1885).

A very systematic survey of the Caspian Sea must be mentioned.

It can be found in the publication "Hydrographical Exploration of the Caspian Sea," by Admiral Trashingow, St. Petersburg, 1878 (in the Russian language).

The study of anomalies in Sweden and Russia is prosecuted with interest by Thalen, Lundquist (Sweden), and Tillo, Fritsche, Lenz (Russia).

ASIA.

The vast regions of north Asia, that is, Siberia and the adjacent countries, have been explored magnetically by Hansteen and Due during their voyage in 1828–'30, by Erman in the years 1828–'31, by Fuss, 1830–'32, Middendorff, 1843–'44, and by H. Fritsche.

The principal works are: Hansteen and Due, *Magnetische Beobachtungen*, Christiania, 1863; and H. Fritsche, *Ueber die Bestimmung der geographischen Länge, Breite und der drei Elemente des Erdmagnetismus durch Beobachtung zu Lande, sowie erdmagnetische und geographische Messungen an mehr als tausend verschiedenen Orten in Asien und Europa, ausgeführt in den Jahren* 1867–'91 *von dem Direktor emeritus des K. Russischen Observatoriums in Pekin*, St. Petersburg, 1893. Although the number of stations of Hansteen and Fritsche is very great, we must make the remark that the chief part of them is confined to the ordinary route from St. Petersburg to Pekin, and to the littoral districts, so that enormous areas of the continent of Asia are still unexplored magnetically. The voyage of the *Vega*, the observations at the north polar station at the mouth of the Lena (Sagastyr) and some very important observations of Gen. Pertjon in the deserts of Central Asia have added new materials, but we must wait till a survey of these large regions can be undertaken.

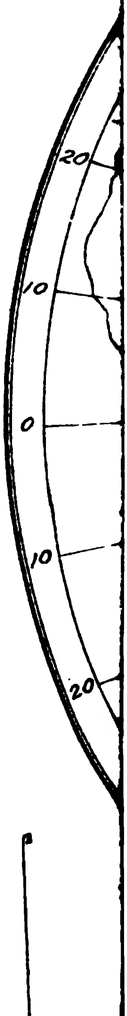
For China the chief observations are also due to H. Fritsche who was director of the Observatory of Pekin from 1867 till 1883, but they do not embrace the western continental parts of China.

Japan is in possession of two magnetic surveys. The first (1882–'83) based on 182 stations has been published by Naumann: *Die Erscheinungen des Erdmagnetismus in ihrer Abhängigkeit vom Bau der Erdrinde*, Stuttgart, 1887, and "Notes on secular changes of magnetic declination in Japan," Transactions of the Seismological Society of Japan, Vol. v, 1882. The second, under the direction of Prof. Knot, was executed in the year 1887 and published in the "Journal of the College of Science," Japanese University, Vol. II, Pt. III.

A magnetic survey of the Indian Empire was made by the brothers Schlagintweit in their work, "Results of a Scientific Mission to India and High Asia," undertaken 1854–'58, Vol. I, London, 1861; but in more recent time such a survey has not been repeated.

It remains to record the two surveys that exist for the Indomalaiian Archipelago, the one due to Elliot and the other to Van Rijcke-

Plate X



vorsel. The publications are entitled, "Magnetic Survey of the Eastern Archipelago, 1846–'49," with 10 plates, Phil. Trans., Lond., 1881. *Verslag von Zijne Ex. den Minister van Kolonien over eene magnetische Opneming van der Ind. Archipel*, 1871–'79. K. Akad. Wet., Amsterdam, 1879–'80.

CHART.

On the accompanying chart (XIV) I have endeavored to represent graphically the present state of our knowledge of the magnetism of Europe and Asia. The surveys are distinguished as first and second rate. We see that Great Britain, France, and part of Germany are in possession of first rate surveys, and all other parts of Europe of second rate magnetic surveys (generally speaking). In Asia there are the Indian Empire and Archipelago, and Japan, which have been systematically covered with magnetic stations. All other boundaries of Asia are only explored by routes, or on their shores, and, as seen, the greatest part of the continent of Asia is still dark as regards magnetism.

In this paper I have briefly but broadly summarized the state of knowledge existing at the present time in the branch assigned to me.

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## 3.—THE INTERNATIONAL POLAR EXPEDITIONS, 1882–'83.

Dr. C. Börgen.

Ever since Capt. Sabine, in Parry's expedition (1819–'20), made his celebrated pendulum and magnetical observations, it has been deemed essential for polar expeditions to bring home more or less extensive observations in meteorology, terrestrial magnetism, and other branches of geophysical science. In passing may be mentioned James Clarke Ross' brilliant discovery of the magnetic pole; Kane's meteorological and magnetical observations, gained under the greatest difficulties and hardships during the two Grinnell expeditions; the results of the British search expeditions in the Arctic Archipelago, and later on to the northernmost point of Grinnell Land; of the Swedish expeditions to Spitzbergen, the German expedition to East Greenland, the Austrian to Franz Joseph Land, Nordenskjöld's brilliant circumnavigation of Asia, and of many other expeditions which it would lead too far to mention here.

The lack or scarcity of an indigenous population in the high north, which in nowise is able or even inclined to give any difficulty to the traveler, the mighty support which the presence of a ship with its numerous crew and its materials gives to any enterprise, the necessity of a stay of many months at the same place, the desire for occupation during the long winter months, are circumstances which greatly promote and even provoke researches in physical and meteorological

sciences in a region where extreme phenomena force themselves upon the dullest mind.

But up to 1882 every expedition worked for itself. It was an exception when several expeditions were at the same time at different places in the north, and even when this happened a common working plan was wanting. Nevertheless the results brought home by the numerous expeditions to the Arctic regions were of the highest value, because they permitted us to gain a general idea of the distribution of the meteorological elements as well as of the magnetical forces, and of the variations they undergo, not only from place to place, but at the same place from time to time. It had long since been recognized that a real progress in the knowledge of the causes and the connection of the phenomena could be hoped for only by the co-operation of many observers in different parts of the globe working on the same plan and, as far as possible, with similar instruments and at the same time. This had led, on the part of terrestrial magnetism, to the foundation of the *Magnetische Verein* in 1835 through the exertions of Von Humboldt and Gauss, and in meteorological matters to the institution of extensive systems of observing stations in the different countries. It would lead too far to give here even a short account of the brilliant researches and scientific discoveries we owe to these common exertions, which were, and in a much higher degree in our day are, directed by the same plan everywhere. They have elevated meteorology from being a mere collection of facts and hypotheses to the rank of a real science, and have prepared for terrestrial magnetism the ground on which the last great enterprise in 1882–'83 was built up. In the following lines I propose to give a short account of the history of the enterprise and of the results gained by the numerous expeditions.

When in 1874 the Austrian Arctic explorer, Lieut. Weyprecht, returned from his attempt to reach the North Pole by way of the Nova Zembla Sea—an attempt which led to the unexpected discovery of Franz Joseph Land—this excellent man, in the course of the reduction of his scientific, more especially his magnetical, observations, came to the conclusion that all observations made by a single expedition must be regarded as nearly worthless, and that only by the co-operation of several expeditions placed at fixed stations around the pole a result equivalent to the cost might be reached.

At the meeting of the German Association of Naturalists and Physicians, held in Gratz in 1875, he gave forcible expression to this view, denounced the former geographical mode of exploration as useless and irrational, and formulated his proposal to alter entirely the principles of Arctic research, to leave off all geographical discovery, and to devote the whole energy to scientific, especially physical, observations, which should be carried on according to a common plan and simultaneously at a series of fixed stations around the pole.

It is but due to historical truth to state that exactly the same views, but not so hostile to geographical research, had been expressed by Prof. Neumayer in a paper entitled, *Die geographischen Probleme innerhalt der Polarzonen in ihrem inneren Zusammenhang beleuchtet*, read in Berlin, the 25th of February, 1874, or one year and a half before Weyprecht, and published in *Annalen der Hydrographie*, 1874, p. 51, etc. The only difference between Weyprecht's and Neumayer's views is this, that the former restricted the stations to the northern polar area, while the latter strongly urged the necessity to extend the observations also to the Antarctic zone. On the other hand, it must be stated that Weyprecht had no knowledge of Neumayer's paper when he made his proposal at Gratz, and that in the subsequent time both of these excellent men heartily co-operated to put the plan into execution.

It would lead too far if we should follow the development of Weyprecht's plan step by step; suffice it to say that it found favor in scientific circles, and was brought before the International Meteorological Congress, which assembled in Rome in April, 1879. The congress expressed its high sense of the importance of the question raised, but could not adopt a resolution as the members were without instructions from their respective governments. It was, however, recommended that a second international congress should meet in October of the same year in Hamburg, in order to consider the question, and to develop a definite plan which might be recommended to the governments for execution.

This congress did accordingly meet in Hamburg, October 1, 1879, the following states being represented: Austria, Denmark, France, Germany, Netherlands, Norway, Russia, and Sweden. The outcome of the deliberations of this meeting was a programme for the observations, which, with a few unimportant alterations, was adopted for execution. A resolution was adopted that the enterprise should be regarded as secured when at least eight stations could be erected. Moreover, the congress constituted itself as an international commission for all questions which required international accordance, Prof. Neumayer being elected president.

In August, 1880, a second meeting of the International Commission was held in Berne, the same states being represented as in Hamburg. The most important resolution taken was that to postpone the enterprise, which originally was intended for 1881–'82, to August, 1882, to September, 1883. Instead of Prof. Neumayer, who resigned the presidency, Prof. Wild, of St. Petersburg, was elected president of the Commission. It was stated that the following states had resolved, definitely, to erect stations: Austria (through the munificence of Count Wilczek), Denmark, Norway, one station each, and Russia, two stations.

In May, 1881, the condition of at least eight stations could be announced fulfilled, and so the enterprise was secured. At the same time a third meeting of the International Commission was convoked at St. Petersburg for August, 1881. At this meeting the programme of observation was definitely settled, and the president communicated to the committee that it was highly probable that besides the eight stations already definitely chosen, there would be established one station by England and Canada jointly, one in East Greenland by Germany, and two stations in the Antarctic Ocean by France and Germany. Further, it was announced that the United States co-operated by the erection of two stations, one at Point Barrow, Alaska, and one in Lady Franklin Bay, which had started for their places of destination in June, 1881, the first under command of Lieut. Ray, the other under command of Lieut. (now General) Greely. Both expeditions were intended for three years, the middle one corresponding to the international polar year.

So the great enterprise was in a fair way to realization, nine stations having been definitely chosen (Point Barrow, Lady Franklin Bay, Upernavik or Godthaab, Fort Rae, Jan-Mayen, Spitzbergen, Mossel Bay, Bossekop, Möller Bay, Nova Zembla, and the mouth of the Lena), three others (East Greenland, Cape Horn, and South Georgia) being probable. Circumstances necessitated for some of the expeditions the choice of other localities, which will be mentioned hereafter.

The enterprise sustained a heavy loss by the premature death of Lieut. Commander Weyprecht, which occurred on the 29th of March, 1881. To his untiring exertions and his unselfish devotion it is in a great measure due that this great international enterprise could be realized, and it is only just to acknowledge here the eminent services Weyprecht has done for it, while expressing a deep regret that it was not allotted to him to see his scheme completed. In his place his friend and comrade Lieut. Commander von Wohlgemuth was entrusted with the command of the Austrian expedition.

At last France, the Netherlands, Finland, and Germany declared definitely their intention to establish, the first three states, one station each (Cape Horn, Dickson Harbor at the mouth of the Yenisei, and Sodankylä); the latter, two stations (either East Greenland or Cumberland Sound and South Georgia). By the accession of these five stations the total number of stations to be established rose to fourteen. Besides her two full stations, Germany erected a secondary station, chiefly for meteorological work and observation of auroras at Nain, Labrador, the missionaries at the other places in Labrador consenting to co-operate by making meteorological observations according to the system of stations of the second order, which are continued up to the present time. For observations of auroras in

co-operation with the Norwegian station at Bossekop, Mr. Sophus Tromholt, then of Bergen, during the winter of 1882–'83, took residence at Kantokeino, about 1° south of Bossekop.

Besides the above-named polar stations a large number of existing observatories in middle latitudes all over the globe declared their readiness to co-operate with the polar stations, enlarging and accommodating their working programme to correspond with that prescribed for the latter. It would lead too far to enumerate all these stations, an omission which seems to be the more justifiable, as only from a few of these, mentioned hereafter, at least as far as the author knows, the results have been published.

The programme for the observations, as fixed by the conferences at Hamburg and St. Petersburg, is given in the following lines, very nearly in the words of the "Communications from the International Polar Commission," omitting, however, the passages relating to purely meteorological observations, which form no part of this report.

### I.—Obligatory observations.

Sec. 1. The observations are to begin as soon as possible after August 1, 1882, and to be continued as long as possible after September 1, 1883.

Sec. 2. The hourly magnetical and meteorological observations may be made according to any time, but on term days the magnetical observations are to be made according to mean civil Göttingen time. Term-days are the 1st and 15th of each month, with the exception of January, when the first monthly term is to be held on the 2d instead of the 1st.

Sec. 3. The expeditions are free to choose the order of their observations as they think fit.

Sec. 4–15. Meteorological observations prescribing hourly observations of barometer, thermometer (dry and wet), hygrometer, wind, clouds, weather, rainfall, etc.

Sec. 16. The absolute declination and inclination should have an accuracy of 1′, the horizontal intensity that of 0.001 of its value.

Sec. 17. It is strongly urged to make a series of magnetical measurements in the neighborhood of the observatory in order to prove or disprove the existence of any possible local influence.

Sec. 18. The determinations of the absolute values of the magnetical elements ought to be effected in closest connection and synchronously with readings of the variation instruments, so as to render it possible to reduce the readings of the variation instruments to absolute values, or, in other words, to determine the values of the zero points of the scales of these instruments. Absolute measurements should be made so frequently that any changes which may occur in the values of the zero points of the scales may be detected with sufficient accuracy.

Sec. 19. The observations of the variations should extend to all three elements of terrestrial magnetism, and every station should be provided with two systems of instruments in order to avoid the risk of interruption of the observations by accident, the two systems to be compared from time to time by simultaneous readings.

Sec. 20. The variation instruments should have small needles and the variations of horizontal force should, at least in one system, be observed by means of a unifilar apparatus with deflecting magnets. As very large disturbances may be expected the scales should extend at least 5° to either side, and as the deviation even may exceed this limit, measures should be taken to observe even such larger excursions of the

needles. The instruments should be so arranged that the simultaneity of the readings of the three instruments may be facilitated as far as possible.

SEC. 21. During the whole time the variation instruments should be read every hour. It is desirable to make two readings with an interval of several minutes, *i. e.*, a few minutes before and after the full hour.

SEC. 22. The 1st and 15th of each month are fixed as term-days (only in January the 2d is to be taken instead of the 1st), the days being counted from midnight to midnight of Göttingen mean civil time. The readings are to be taken every fifth minute at the exact minute, and the three elements should be read as quickly as possible one after the other in the following order: Horizontal intensity, declination, vertical intensity.

SEC. 23. On term-days, during a whole hour, the observations should be made every 20 seconds, at least, for declination. The hour of increased observation is not the same on all term-days, but changes in the following manner: August 1, 12 m. to 1 p. m., Göttingen mean time; August 15, 1 p. m. to 2 p. m.; September 1, 2 p. m. to 3 p. m.; and so on for each term-day, one hour later than at the preceding one.

SEC. 24. Auroras should be observed every hour with regard to shape, color, and motion, the position to be given in true bearings. The brilliancy is to be estimated according to the scale 0–4 (*vide*, Weyprecht, *Praktische Anleitung zur Beobachtung der Polarlichte*). If the general illumination by the auroral display be sufficient to read printed matter, its brilliancy should be estimated thereby, using the method serving for testing the eye sight (*i. e.*, by the scale of Prof. von Jaeger, in Vienna).

SEC. 25. On term-days continued observations of auroras should be carried on.

SEC. 26. Especially remarkable instances of auroras and magnetical disturbances should be made the subject of special investigation, so as to render it possible eventually to trace the connection between the variations of the phases of both phenomena.

SEC. 27. Astronomical observations.—As the closest possible simultaneity of the observations is a main object of the whole enterprise, determinations of geographical position and time are to be made by fixed instruments (transit or universal instrument), without, however, excluding the use of good reflecting instruments. Every effort should be made as quickly as possible to determine the longitude of the place with sufficient accuracy for the purpose of the expedition.

II.—ELECTIVE OBSERVATIONS.

SEC. 28. The conference recommends that the following observations should be stated as highly desirable in the instructions to the different expeditions:

SEC. 29. Meteorology.—Variation of temperature with height; temperature of the soil, of the snow and ice at the surface and in different depths; insolation, evaporation, thawing of the ice in summer.

SEC. 30. Magnetism.—Occasional absolutely simultaneous readings of all three elements of terrestrial magnetism, in order to determine accurately the relation between variations of horizontal and vertical intensity.

SEC. 31. Observations of earth currents in connection with the magnetical and auroral observations.

SEC. 32. Hydrographical observations.—Currents, thickness of ice, temperature and salinity of the sea water, tides, if possible by self-registering apparatus.

SEC. 33. Auroras.—Measurements of the height of auroras by two observers placed at a distance of say five kilometers from each other in the direction of the magnetic meridian; spectroscopic observations.

SEC. 34. Electricity of the atmosphere, astronomical and terrestrial refraction, twilight, length of the seconds pendulum, glaciers; collection of air samples for subsequent analysis; observations and collection of objects of natural history.

These are the main points of the programme. With regard to reduction and calculation of the observations, the use of Gauss'

metrical units, and for meteorological observations, millimeters and centigrades, were recommended.

This programme was accepted by the St. Petersburg conference as a basis of the work of the expeditions.

The table (p. 485) contains the name and geographical positions of the stations, together with the name of the country by which the expeditions were sent out, who defrayed the costs, under whose direction the scientific work was placed, and the names of the leaders of the expeditions.

A few remarks regarding the instruments used, which were not everywhere of the same construction, may perhaps be of some interest.

For the absolute determination of declination and horizontal intensity most stations used a magnetic theodolite much after Lamont's construction, only at Cape Horn a theodolite of a somewhat different, and in the opinion of the present writer not altogether happy, construction was used. There is only on one side of the needle a support of the deflecting magnet, so it is necessary to turn this support through 180° to bring it to the other side—an operation by which slight alterations in the arrangement may occur only too easily, which will vitiate the results. For determination of the inclination at most stations a dip circle was used; only the two German expeditions were provided besides with an earth conductor and vibration galvanometer according to W. Weber, which gave every satisfaction and doubtless are the instruments of the future.

According to the programme, the variations of the magnetic elements should be observed by instruments according to Lamont's system, consisting of a unifilar for declination, unifilar with deflecting magnets (perpendicular to the needle) for horizontal intensity, and unifilar with deflecting rods of soft iron for vertical intensity. Besides this chief system a second set of instruments should be provided, the composition of which was left to the several commissions charged with the equipment of the expeditions. Most of the expeditions were provided with two sets of Lamont's apparatus, only the two Russian and Finnish expeditions had for the second system a unifilar for declination, a bifilar for horizontal, and a Lloyd's balance for vertical intensity. The French expedition to Cape Horn had two sets of apparatus, one for direct reading, the other for photographic registration; the former consisting of unifilar, unifilar with deflecting magnets, inclined 45° to the needle instead of being perpendicular to it as in Lamont's system, and a Lloyd's balance, the latter comprising unifilar, bifilar, and balance. The German expeditions had two systems of Lamont's apparatus, that to Kingua-Fjord being provided besides with a Lloyd's balance. At Kingua Lamont's apparatus for vertical intensity (iron rods) proved quite

useless, and the observations have been left out of consideration. Fortunately, Dr. Giese had in time remarked this, and from February Lloyd's balance was read regularly, thus securing at least seven months of good values for the vertical intensity. It is to be feared that through this insufficiency of Lamont's apparatus, the vertical intensities of several stations may be impaired.

For observations of auroras the Norwegian, Swedish, and Finnish expeditions and Mr. Tromholt were provided with a "Nordlicht-Theodolit" constructed by Prof. Mohn, by means of which the position, azimuth and altitude, of the culminating point of auroral arcs and other phenomena were determined, while for the German Labrador expedition a "meteorograph," after Neumayer's construction, was used. Most of the expeditions had good spectroscopes at their disposal, with which measurements of the lines of the auroral spectrum were taken.

Regarding the individual history of the expeditions our remarks must necessarily be very short. In fact, by far the greatest part of them reached their point of destination without difficulties, and carried on their work in safety until their return home in the autumn of 1883, which was effected without accidents. Only two of the expeditions must be mentioned a little more in detail, one because it did not reach its place of destination and was obliged to winter in the ice pack without being able to fulfill the whole extent of the programme; the other on account of the tragical events of the return journey. The first is the Dutch expedition which was bound for Dickson Harbor, at the mouth of the Yenisei River. The expedition set out on board of the steamer *Varna*, and reached in good time the Kara Sea, where they fell in with the Danish steamer *Dijmphna*, of the polar expedition under command of Lieut. Hovgaard. Both steamers got beset in the ice and were obliged to winter in the Kara Sea, being drifted about with the pack. Under these circumstances magnetical observations, which require a fixed position, were out of the question, but the meteorological work was carried on according to the programme. The *Varna*, in December, 1882, by heavy ice pressure, became leaky and was abandoned, the members of the expedition and the crew being hospitably received on board the *Dijmphna*. In the beginning of August, 1883, the expedition commenced its retreat in boats, and was ultimately brought to Vardo by the steamer *Louise*, which was obliged to give up its voyage to the Yenisei on account of a broken shaft.

The two American expeditions had already set out for their respective destinations in July, 1881, and had arrived respectively, in August and September at Fort Conger, Lady Franklin Bay, and at Uglaamie, Point Barrow. It had been arranged that every summer a relief expedition should start for each of these stations in order to

replenish provisions and relieve such persons as might wish to return home. The Fort Conger relief expedition of 1882 should, moreover, bring out a complete set of magnetical variation instruments to enable the expedition to fully carry out the international programme. While the expedition to Point Barrow reached this place the relief expeditions to Fort Conger failed on account of the state of the ice both in 1882 and 1883. Lieut. Greely was, in consequence, obliged to give up the station in August, 1883, and try to meet the relief vessel on its way up Smith and Robeson Channels. This, however, was unfortunately nipped in the ice, and sunk so rapidly that the crew only with difficulty saved their lives, and had to retreat southward without being able to lend any help to the party of Lieut. Greely. By this misfortune the latter was brought into a most dangerous situation, and passed a most fearful winter at Cape Sabine, on the west side of Smith Sound, where he was at last, in June, 1884, rescued in a starving condition after the greater part of the party had succumbed to sickness and want.

The lamentable story of the frightful sufferings which Lieut. Greely and his party had to undergo and the heroic courage with which these were borne form a most touching page in the history of Arctic research. The sense of duty and of the importance of scientific work, which is manifested by the fact that all scientific observations and most of the instruments were saved by the party under the most fearful circumstances, entitles Lieut. (now General) Greely to the greatest admiration of the scientific world. On account of the failure of the relief expedition in 1882, and the consequent want of suitable magnetical instruments, Lieut. Greely was not in the position to carry out the whole magnetical programme, but was obliged to limit the observations to those of variations of declination and inclination, the latter being observed by means of a dip circle from October, 1882, to May, 1883, inclusive. The absolute horizontal intensity was determined several times every month, and with regard to the variations of the declination the international programme was strictly adhered to.

In the last paragraph of the programme it had been proposed that after the return of the expedition the International Commission should hold a conference with regard to common measures for the publication of the results. This conference was held in April, 1884, in Vienna, and was attended, not only by the members of the International Commission, but also by the leaders of some of the expeditions and some other persons interested in the proceedings. The conference received with the greatest satisfaction the intelligence that all expeditions, with the above-mentioned exceptions, had been successful, and it may be stated at once that full agreement was arrived at for all the points of a programme which had previously been brought to the knowledge of the participants of the conference.

The main points agreed on by the Vienna conference may shortly be stated as follows, as far as the magnetical observations are concerned.

The observations, both of absolute values and of variations, should be published *in extenso*, the latter being given fully reduced for temperature and in absolute measure, always a full amount of the methods used in observation and reduction being given. The hourly values as well as the 5-minute values of the term-days should be given for declination in degrees, minutes, and tenths of minutes, counting from 0° to 360°, from north through east, south, and west, for horizontal and vertical intensity in electrical, or C. G. S. units, instead of Gauss' units as formerly proposed. Regarding time, it was resolved that the term-day observations should be given in Göttingen mean civil time, as prescribed by the programme, all other observations, such as the hourly values, in local time. Those expeditions which had made all observations, according to Göttingen time, should give the values nearest to a full hour of local time under the head of this hour, noting the correction to local time at the head of the table. For each hour the monthly mean, and for every day the mean of the twenty-four hourly values and the general monthly mean should be given, also the greatest and least values observed in every day and their difference.

The term-day observations should be given both in numbers and by curves in order to facilitate a comparison of the observations at different places, the same to be done for observations of larger disturbances, among which the enormous disturbance from November 15–18, 1882, which was felt all over the earth, is particularly conspicuous.

Regarding the auroral observations it was determined to give a simple notice whether an aurora had been visible along with the hourly cloud observations. For other points it was left to the several commissions charged with the publication of the results to find a suitable form of publication, the same being resolved with regard to the elective observations.

The discussions which led to these resolutions, by which a most desirable accordance of the several publications was secured, were full of interest and touched upon many questions which presented difficulties or were open to different interpretation; also new methods of discussion of the results were proposed and considered, of which one or the other has proved a new departure. One question on which the views were very different was, what ought to be regarded as a disturbance, the methods hitherto employed to discuss and exclude the disturbances being those of Sabine, Lefroy, and Buys-Ballot. It would lead too far to follow here the most interesting discussion of this important and difficult question, the more so as a general agree-

ment was not arrived at, but the discussion did much to clear up the meanings. Among the new methods proposed for discussing and reducing observations we may mention those of Prof. Wild of St. Petersburg, and of Dr. Van der Stok of Batavia, which latter was brought to the knowledge of the conference by Dr. Snellen. Wild's method consists in selecting for each month certain days, which by inspection of the photographic curves of a central observatory, show themselves to be free from disturbances, to derive from these the normal diurnal variation of the three elements, and regard the deviations from this as disturbances that may be afterward discussed according to any suitable method, *i. e.*, that of Buys-Ballot. I must refrain from giving an account of Van der Stok's method, the more so as it, in my knowledge, has only been employed in the discussion of the Batavian observations. Wild's method has, likewise, not been universally adopted, but has been used along with the ordinary method of employing all observations by several stations.

The publication of the observations of the different stations has been carried out in accordance with these resolutions, and a stately number of volumes has been the result. It was thought possible at Vienna to have the publications completed toward the end of 1886, but a much longer time has been consumed, and, in fact, a few publications are actually behindhand.

A great boon it will prove to every one who subsequently makes use of this vast amount of numbers to find them expressed in the same measures, and arranged in practically the same manner, in the publications of all nations. It is a matter of regret that in this respect the volume containing the observations at Point Barrow forms an exception, the observations of variation being expressed in scale numbers, and for intensity are even left unreduced for temperature. I am afraid that the consequence of this will be that the Point Barrow observations will be neglected, and the care and labor bestowed on their collection will have been spent in vain. It is much to be hoped, and I would strongly urge, that means may be found to republish these observations conformably with the international system.

Another point which greatly assists the subsequent utilization of the treasures contained in these volumes is this, that in most of them the observations on term-days and of the larger disturbances, besides being given in numbers, have been represented by curves drawn to the same scale. By this arrangement, the comparison of the alterations of the magnetic elements at different stations at the same moment is a matter of very little trouble, and it can not be doubted that valuable and important results may be detected in a comparatively easy manner. Also, the mean diurnal variations of the magnetic elements have been represented by curves for each month,

although not to the same scale in different publications. This enables the student not only at a glance to see the difference from month to month at the same place, but also to trace the differences which appear from place to place.

An inspection of the term-day curves, as well as of the larger disturbances at different stations, will show how far the similarity of the movements of the needles brought to light by the observations of the magnetical association in the third decennium of this century holds good for stations within or near the Arctic circle, and may perhaps lead to most important results with regard to the seat of the disturbing force, the influence which the constitution of the earth's crust, and the distribution of land and water, may exercise on the manifestations of the magnetic forces. As yet very little has been done to bring the treasures that lie hidden in that vast amount of numbers to light. It is to be hoped that soon some one may find courage to attack the many unsolved questions of terrestrial and cosmical magnetism; he will find ample material in the volumes of the great international enterprise of 1882–'83.

There is one point, however, which will require critical skill, and which may tend to diminish somewhat the value of a part of the observations, viz, the unsuitability of the instruments for variations of vertical intensity. Unfortunately, the international commission preferred Lamont's system, and although it was prescribed only for horizontal intensity, most of the expeditions also adopted Lamont's plan for observation of variations of vertical intensity by iron rods as deflectors, a general mistrust reigning against Lloyd's balance. I am afraid that by this circumstance the vertical intensities observed at several stations will be of little value.

As has been stated before, the regular observations which were prescribed by the programme as obligatory were accomplished by all stations strictly in accordance with the programme, and as this has been fully given above, I need not make any further remarks on them. It may interest the reader to have a list of the mean values of the magnetic elements for every month and for all stations for which they have been published, which is given on page 484.

Most of the publications contain extensive observations and descriptions of auroras, amply illustrated by designs of characteristic forms and charts, showing the distribution of the auroral display at certain moments among the stars. In several volumes we find a discussion of these observations (by Dr. Koch for Nain and Kingua, by Carlheim-Gyllenskjöld for Cape Thordsen, by Dr. Bobrick for Jan-Mayen, and by Paulsen for Godthaab, Nennortalik, and Angmagsalik), in which different periods of auroral displays are traced, by which the results of other investigators have been confirmed. But we must not omit in this connection to mention the brilliant results found by Paulsen

and Carlheim-Gyllenskjöld with regard to the height of the aurora above the ground. The former of these gentlemen observed at Godthaab, using a base line of 5.8 kilometers, the latter at Spitzbergen with a base line of only 575 meters. The result at both stations was that the aurora sometimes came very far downward, one observation giving the height only 0.6 kilometer, while by others it was stated to be 1 or 2 kilometers high; however, very much greater heights, up to 50 kilometers and more, were not wanting. This is a brilliant confirmation of former observations of auroral light, enveloping near mountains, or lying, seemingly, between the observer and some distant object which, hitherto, had been open to some doubt as being brought about by some optical illusion. Moreover, Paulsen's and Carlheim-Gyllenskjöld's observations seem to afford an important support to Edlund's theory of auroras.

It is a remarkable fact that at the two stations in the Southern Hemisphere no auroras were observed.

Besides the regular obligatory observations, much important work has been done by some of the expeditions in other directions. Earth currents have been observed by Dr. Giese at Kingua-Fjord and by Prof. Lemström at Sodankylä. The latter have not yet been published, and of the former it must suffice to mention that observations were made both of the currents occurring in two cables lying north to south and east to west, and of the induction currents caused by variations of the vertical intensity in a ring cable forming a polygon of large area. The latter observations proved to be of importance, because they gave the incontestable proof that Lloyd's balance really gave trustworthy values of the variations of the vertical intensity, while Lamont's system was quite worthless.

We can only mention in passing the numerous observations and investigations which were made besides the meteorological and magnetical work. With the exception of Fort Rae, all other stations were situated on the seashore, and we, therefore, find that the observation of the phenomena has everywhere found due attention, partly self-registering tide-gauges were set up, partly a scale was read every hour, at least, during some months. Together with the tidal observations, the temperature and the salinity of the sea water were observed. At several stations, Fort Rae, Lady Franklin Bay, Spitzbergen, Sodankylä, Cape Horn, etc., the temperature of the soil in different depths was observed regularly; radiation thermometers were likewise read at most stations. Pendulum observations were instituted by the expeditions to Lady Franklin Bay and South Georgia. Collections of objects of natural history and of anthropological and ethnographical interest were largely made where occasion offered. In this respect the French expedition to Cape Horn ranks foremost by its investigation of the life and manners of the hitherto rather unknown Fuegian races.

The amount of carbonic acid contained in the air on shore and over the Atlantic Ocean was investigated by the French expedition to Cape Horn. Physiological observations of the influence of an Arctic winter on the human organism were the object of investigation of the Swedish expedition to Spitzbergen. Numerous other special observations must be left unmentioned here. We will only refer last, but not least, to the observation of the transit of Venus, December, 1882, which, by good fortune, the French and German expeditions to the South were able to make; especially the latter, thanks to its good equipment, was enabled to bring home a valuable contribution to the observation of this rare phenomenon by a series of heliometric measurements of the distance of the centers of the sun and Venus.

It will be seen even from this cursory enumeration what treasures, what an enormous mass of scientific work, these volumes contain, which will yield material enough for investigation for many years to come.

The International Polar Commission met again in September, 1891, in Munich. Of the four questions which were discussed the most important was the second, deliberations about the means to bring about a general discussion of the results of the expeditions, perhaps by putting a distinct prize question. It was acknowledged on all sides that this was a most desirable and important end, and it was resolved to constitute two committees, one for the magnetical, the other for the meteorological work; the former consisting of Gen. Greely, Prof. Neumayer, and Prof. Mascart, the second of Gen. Greely, Prof. Neumayer, and Prof. Mohn.

Moreover, it was resolved that the archives of the Commission, consisting of a number of the publications of the several stations, should remain as heretofore, with the Central Physical Observatory at St. Petersburg under the superintendence of the Imperial Academy of Science.

Finally, on the instigation of Prof. Neumayer, it was resolved: "That the International Polar Commission expresses its conviction that the scientific exploration of the south polar regions with regard to terrestrial magnetism and meteorology of the globe ought now to be promoted with every possible energy."

The International Polar Commission, regarding its mandate accomplished, was then finally dissolved.

When we look at the outcome of the great efforts of the expeditions of 1882–'83, it is scarcely possible to realize fully, at this time, the value of their observations. This will be brought to light by the discussions which will, it is to be hoped, be published in the future. It is scarcely to be doubted that the results will prove in many directions fruitful and important, although, on the other hand, they will doubtless disclose many gaps and raise many questions, which must find

their solution by a repetition of the enterprise, which, it is strongly to be hoped, will in the future be set on foot.

On one point, however, the expeditions have already given valuable hints, namely, on the choice of instruments for observing the variations of terrestrial magnetism. Lamont's system must not be used again, not even for variations of horizontal intensity, because the computation of the variations depends on the readings of two different instruments, whereby in the Arctic regions, where the needles mostly are in more or less violent motion, considerable errors may be introduced when the readings of the instruments are not absolutely simultaneous. With regard to vertical intensity, which depends in Lamont's system on the reading of three instruments, this is in a much higher degree the case, and at all events the iron rod should find no favor in the future. For the Arctic regions instruments are required which give the value of the element they are intended for at any given moment by itself without the intercession of a second instrument. In this respect the bifilar and Lloyd's balance claim first consideration, but perhaps even better instruments may be at our disposal in the future. It should be very earnestly taken into consideration to replace ocular observation by photographic records, and I think there can be very little doubt that this plan will be adopted.

Another point which, it can not be doubted, must find much more consideration in a future enterprise than it did in 1882–'83 is the erection of stations in the south polar regions. In 1882–'83 only two stations, Cape Horn and South Georgia, were occupied in the Southern Hemisphere, but they were situated in a region which is very far from the foci of magnetic force and from the southern magnetic pole. Much as we are to be thankful that magnetical observations from higher southern latitudes than were hitherto available have been gained, these stations were too far from the zone of maximum disturbance to be able to yield any very important contribution to the solution of questions of terrestrial magnetism. It is much to be hoped that the Antarctic regions may be explored more fully in geographical respect, in order to enable the choice of stations, if possible, within the Antarctic Circle and nearer to the focus of magnetic activity than any now available.

The international enterprise of 1882–'83 has at all events taught one great lesson, namely, what may be effected when the nations join themselves to common work and setting aside all jealousies work enthusiastically to the same end. Let us hope that this lesson at least may not be lost, and that in the future the watchword of scientific research may be, even more than it has been in the past, *Viribus unitis!*

*Mean values of magnetic elements*, 1882–'83, *at the International Polar Stations.*

| Station and magnetic element. | 1882. September. | 1882. October. | 1882. November. | 1882. December. | 1883. January. | 1883. February. | 1883. March. | 1883. April. | 1883. May. | 1883. June. | 1883. July. | 1883. August. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cape Thordsen:** | | | | | | | | | | | | |
| Declination | 347° 20.1′ | 347° 21.1′ | 347° 17.7′ | 347° 10.7′ | 347° 9.4′ | 347° 14.2′ | 347° 20.5′ | 347° 16.6′ | 347° 19.6′ | 347° 21.0′ | 347° 20.9′ | 347° 22.2′ |
| Horizontal intensity | 0.08911 | 0.08883 | 0.08839 | 0.08855 | 0.08865 | 0.08873 | 0.08886 | 0.08903 | 0.08917 | 0.08916 | 0.08917 | 0.08915 |
| Vertical intensity | 0.52860 | 0.52969 | 0.52907 | 0.52885 | 0.52812 | 0.52991 | 0.53099 | 0.53153 | 0.53189 | 0.53171 | 0.53156 | 0.53177 |
| **Bossekop:** | | | | | | | | | | | | |
| Declination | 355° 53.7′ | 355° 57.2′ | 356° 0.9′ | 355° 57.1′ | 355° 56.3 | 355° 58.3′ | 355° 57.8′ | 355° 57.8′ | 355° 57.7′ | 355° 57.2′ | 355° 58.7′ | 355° 59.1′ |
| Horizontal intensity | 0.12095 | 0.12077 | 0.12061 | 0.12093 | 0.12108 | 0.12086 | 0.12090 | 0.12084 | 0.12091 | 0.12098 | 0.12086 | 0.12085 |
| Vertical intensity | 0.50491 | 0.50447 | 0.50492 | 0.50508 | 0.50496 | 0.50469 | 0.50448 | 0.50442 | 0.50404 | 0.50393 | 0.50423 | 0.50451 |
| **Sodankylä:** | | | | | | | | | | | | |
| Declination | 1° 27.9′ | 1° 30.8′ | 1° 34.7′ | 1° 31.3′ | 1° 29.7′ | 1° 31.3′ | 1° 30.2′ | 1° 29.6′ | 1° 30.8′ | 1° 31.0′ | 1° 32.0′ | 1° 32.8′ |
| Horizontal intensity | 0.13354 | 0.13331 | 0.13297 | 0.13339 | 0.13347 | 0.13329 | 0.13342 | 0.13336 | 0.13342 | 0.13355 | 0.13351 | 0.13352 |
| Vertical intensity | 0.49191 | 0.49028 | 0.48993 | 0.49106 | 0.49076 | 0.49052 | 0.49054 | 0.49123 | 0.49075 | 0.49120 | 0.49208 | 0.49202 |
| **Little Karmakul:** | | | | | | | | | | | | |
| Declination | ............ | 15° 0.9′ | 15° 3.8′ | 14° 56.7′ | 14° 54.4′ | 15° 0.4′ | 14° 58.7′ | 14° 58.6′ | 14° 59.8′ | 14° 56.0′ | 14° 58.6′ | 14° 59.1′ |
| Horizontal intensity | ............ | 0.10728 | 0.10729 | 0.10740 | 0.10717 | 0.10728 | 0.19745 | 0.10755 | 0.10767 | 0.10776 | 0.10747 | 0.10750 |
| Vertical intensity | ............ | 0.54211 | 0.54088 | 0.54028 | 0.53968 | 0.53929 | 0.54065 | 0.54083 | 0.54098 | 0.53909 | 0.53892 | 0.53991 |
| **Uglaamie, Point Barrow:** | | | | | | | | | | | | |
| Declination | 81° 22.2′ | 81° 22.6′ | 81° 22.8′ | 81° 22.4′ | 81° 22.0′ | 81° 24.8′ | 81° 25.0′ | 81° 24.5′ | 81° 22.6′ | 81° 23.9′ | 81° 19.2′ | 81° 22.2′ |
| Horizontal intensity | 0.08921 | 0.08977 | 0.08996 | 0.08950 | 0.08931 | 0.08908 | 0.08890 | 0.08931 | 0.08950 | 0.08654 | 0.08908 | 0.08963 |
| Vertical intensity | 0.5882 | 0.5920 | 0.5934 | 0.5899 | 0.5882 | 0.5900 | 0.5890 | 0.5911 | 0.5901 | 0.5919 | 0.5835 | 0.5906 |
| **Fort Rae:** | | | | | | | | | | | | |
| Declination | 40° 35.5′ | 40° 29.9′ | 40° 34.7′ | 40° 22.4′ | 40° 20.0′ | 40° 21.7′ | 40° 18.3′ | 40° 15.9′ | 40° 16.8′ | 40° 19.0′ | 40° 17.9′ | 40° 19.7′ |
| Horizontal intensity | 0.07646 | 0.07639 | 0.07616 | 0.07646 | 0.07645 | 0.07633 | 0.07641 | 0.07658 | 0.07670 | 0.07669 | 0.07659 | 0.07672 |
| Vertical intensity | 0.61815 | 0.61773 | 0.61741 | 0.61748 | 0.61771 | 0.61745 | 0.61795 | 0.61816 | 0.61785 | 0.61795 | 0.61777 | 0.61772 |
| **Kingua-Fjord:** | | | | | | | | | | | | |
| Declination | 287° 57.6′ | 287° 40.6′ | 287° 30.0′ | 287° 37.1′ | 287° 40.7′ | 287° 39.1′ | 287° 42.6′ | 287° 50.5′ | 287° 58.0′ | 287° 56.4′ | 288° 1.9′ | 288° 2.0′ |
| Horizontal intensity | 0.06400 | 0.06387 | 0.06377 | 0.06377 | 0.06368 | 0.06365 | 0.06361 | 0.06374 | 0.06385 | 0.06382 | 0.06383 | 0.06387 |
| Vertical intensity | ............ | ............ | ............ | ............ | ............ | 0.59125 | 0.59201 | 0.59341 | 0.59527 | 0.59448 | 0.59358 | 0.59288 |
| **Jan-Mayen:** | | | | | | | | | | | | |
| Declination | 330° 2.6′ | 330° 4.7′ | 330° 3.9′ | 330° 6.5′ | 330° 5.7′ | 330° 5.1′ | 330° 8.1′ | 330° 8.0′ | 330° 9.3′ | 330° 9.9′ | 330° 11.3′ | 330° 14.9′ |
| Horizontal intensity | 0.09739 | 0.09747 | 0.09713 | 0.09735 | 0.09751 | 0.09734 | 0.09735 | 0.09756 | 0.09764 | 0.09765 | 0.09757 | ............ |
| Vertical intensity | 0.50395 | 0.50408 | 0.50375 | 0.50365 | 0.50242 | 0.50224 | 0.50243 | 0.50282 | 0.50242 | 0.50228 | 0.50226 | ............ |
| **Cape Horn:** | | | | | | | | | | | | |
| Declination | ............ | 20° 12.8′ | 20° 12.4′ | 20° 12.2′ | 20° 11.9′ | 20° 12.8′ | 20° 11.1′ | 20° 10.6′ | 20° 9.6′ | 20° 9.2′ | 20° 9.0′ | 20° 8.5′ |
| Horizontal intensity | ............ | 0.28544 | 0.28532 | 0.28537 | 0.28541 | 0.28530 | 0.28516 | 0.28525 | 0.28535 | 0.28535 | 0.28552 | 0.28553 |
| Vertical intensity | ............ | 0.37878 | 0.37870 | 0.37834 | 0.37801 | 0.37775 | 0.37756 | 0.37738 | 0.37719 | 0.37704 | 0.37689 | 0.37675 |
| **South Georgia:** | | | | | | | | | | | | |
| Declination | 359° 48.0′ | 359° 48.0′ | 359° 48.6′ | 359° 46.8′ | 359° 45.9′ | 359° 45.0′ | 359° 44.3′ | 359° 43.2′ | 359° 41.8′ | 359° 42.3′ | 359° 41.4′ | 359° 40.9′ |
| Horizontal intensity | ............ | 0.25602 | 0.25648 | 0.25677 | 0.25685 | 0.25683 | 0.25682 | 0.25665 | 0.25669 | 0.25659 | 0.25674 | 0.25700 |
| Vertical intensity | ............ | 0.29482 | 0.29478 | 0.29322 | 0.29282 | 0.29486 | 0.29463 | 0.29406 | 0.29400 | 0.29356 | 0.29412 | 0.29409 |

*Geographical positions, etc., of International Polar Stations.*

| Number. | Place. | Geographical position. Latitude. | Longitude. | Sent out by— | Costs defrayed by— | Under scientific direction of— | Leader of the expedition. |
|---|---|---|---|---|---|---|---|
| | | ° ′ | ° ′ | | | | |
| 1 | Cape Thordsen, Spitzbergen | 78 18.5 N. | 15 42.3 E. | Sweden | Merchant O. Smith | Academy of Sciences | Com. Eckholm. |
| 2 | Bossekop, Lapland | 69 57.5 N. | 23 14.8 E. | Norway | State | Meteorological Institute | Ass't Steen. |
| 3 | Sodankylä, Finland | 67 24.5 N. | 26 36.1 E. | Finland | ...do | Finnish Society of Sciences | Prof. Lemström. |
| 4 | Little Karmakul, Nova Zembla | 72 22.6 N. | 52 42.5 E. | Russia | ...do | Geographical Society | Lieut. Andrejew. |
| 5 | Kara Sea | 71 00.0 N. | 64 00.0 E. | Netherlands | ...do | Meteorological Institute | Dr. Snellen. |
| 6 | Sagastyr, mouth of Lena | 73 22.7 N. | 124 5.0 E. | Russia | ...do | Geographical Society | Lieut. Jürgens. |
| 7 | Uglaamie, Point Barrow | 71 17.7 N. | 156 39.8 W. | United States | ...do | Signal Office | Lieut. Ray. |
| 8 | Fort Rae, Great Slave Lake | 62 38.9 N. | 115 43.8 W. | England and Canada. | ...do | Meteorological Office in London | Capt. Dawson. |
| 9 | Kingua Fjord, Cumberland Sound | 66 35.7 N. | 67 19.2 W. | Germany | ...do | Polar Commission | Dr. Giese. |
| 10 | Lady Franklin Bay, Grinnell Land | 81 44.0 N. | 64 45.0 W. | United States | ...do | Signal Office | Lieut. Greely. |
| 11 | Nain, Labrador | 56 32.8 N. | 61 40.8 W. | Germany | ...do | Polar Commission | Dr. Koch. |
| 12 | Godthaab, Greenland | 64 10.8 N. | 51 43.5 W. | Denmark | ...do | Meteorological Institute | Adjunct Paulsen. |
| 13 | Jan-Mayen | 70 59.8 N. | 8 28.1 W. | Austria | Count Wilczek | Count Wilczek | Lieut.-Com. Von Wohlgemuth. |
| 14 | Cape Horn, Orange Bay | 55 31.4 S. | 68 5.7 W. | France | State | Polar Commission | Lieut. Courcelle-Seneuil. |
| 15 | South Georgia, Moltke Bay | 54 31.0 S. | 36 00.0 W. | Germany | ...do | ...do | Dr. Schrader. |

## 4.—THE DISCOVERY OF MAGNETIC DECLINATION MADE BY CHRISTOPHER COLUMBUS.

Fr. Timotheus Bertelli, B[a].

Having received from the committee of the Meteorological Congress the honorable invitation to briefly set forth in a paper of twenty minutes one of the most important things of the past, I turn back to the discovery of magnetic declination, premising the following statement, that, though it will not be possible for me to give in so brief a time and space a proper résumé of the principal historical arguments of the subject, I will endeavor to supply the lack by reference to a previous publication.[1] In the second place, in order to avoid in the future any misunderstanding arising from the confusion of terms, I will note that in the sixteenth century, and in the first half of the seventeenth century, the horizontal displacement of the magnetic needle in respect to the local astronomical meridian (displacement which we designate by the name declination) was then called variously by the writers not only by the name declination, but also by that of variation, verticality, as well as inclination; this last word is now set apart to mean simply the angle of the extremity of the magnetic needle below the horizon in the plane of the local magnetic meridian.[2]

Now, restricting myself to the proposed theme, I affirm, what is already published, that not only the fact of the cosmical phenomenon of magnetic declination, but also its change of value from time to time according to the different longitudes, and its passage over a line of no declination (which for brevity we call agonic[3]), with change of sign from east to west, is due to Christopher Columbus, during his first voyage of discovery of a new continent.[4]

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[1] "Christopher Columbus, Discover of Magnetic Declination, and of its Variation in Space," in the collection of documents and treatises published by the Royal Columbian Commission, Rome, 1892, Vol. II. Part IV. For brevity, I will allude to this work of mine, by the initials C. C., and I will indicate by B. B., Vols. I and IV of the Bulletins of Bibliography of History of Mathematical and Physical Sciences, published. by B. Boncompagni. Rome. 1868–'71.

[2] Although Robert Norman was first able to study accurately this phenomenon in 1576 by means of an inclinometer, the discovery of the fundamental fact, however, is due to George Hartmann, in 1544. See B. B., I, pp. 353–358; C. C., Chap. III, p. 31, note 4.

[3] Although the word isogonic is in use, I prefer the term agonical or agonic, although the former may be of better derivation.

[4] All this I consider the variation of the declination in space; as for its variation with the time in the same place, that was discovered first at Limehouse, in England, by John Burrows, the 16th of October, 1580, and the same was afterwards confirmed by the observations of Edward Gunter on the 13th of June, 1612, and finally, also at Limehouse, it was more accurately shown by Henry Gellibrand on the 12th of June, 1633; yet John Hevelke had made for such purpose some observations in Denmark in 1628 and Petit at Paris in 1630, but the variation taken may be attributed to old instrumental

After having shown the origin of the same explanation, in the voyage of Columbus and in the testimony of the authors who lived at that time,[1] I note that this phenomenon of declination was unknown at that epoch, and even to the Chinese themselves, although from them we have had (as stated in historical documents) the first recognition and the first *rough use* of the directive property of the magnetic needle. In fact, there is only one quotation in their books which at first sight seems to indicate in the author some recognition of the declination, but which when examined and discussed as it ought to be indicates instead precisely the contrary.[2]

Leaving then the most probable date of the introduction of the compass and the floating needle into the Mediterranean and the progressive perfecting which it received from that time until the beginning of the fourteenth century,[3] and afterwards by Christopher Columbus, I will show that the declination was then entirely unknown, as is indicated clearly by all the writers, without exception, who made any allusions to the deviation of the magnetic needle.[4]

I noted also a related subject, namely, the points of maximum action of magnetic intensity, which for that reason were called the *poles*, because they, so it was supposed, were influenced and attracted toward the poles of the heavens, regarding the magnet as an image of the heavens, and thus by the theory of the attractions of like they must indicate the homonymous points. This theory existed in the time of Christopher Columbus[5] and also continued to later times.

To confirm this medieval theory, I translated some passages of a famous document of 1219, entitled *Petri Peregrini de Maricourt, Epistola de Magnete*, wherein is collected the most and the best of the science which they had at that time in Italy concerning the loadstone. This document was explained by me in 1868 and 1871, and referred to in the memoir of 1892,[6] already cited.

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defects. (*Cf. Kircher, Magnes.* Rome, 1664, p. 308. Riccioli. *Geogr. et Hydrograph. reformatae.* Bononiae, 1661, Lib. VIII, 2 XI, § XVI. Trans. Phil. Soc. London, 1676, No. 127, p. 677.) Gassendi himself also verified the fact of the variation in 1649, but had received before that time news from Valesio of the observations made in England. Of the variation of declination underground, and of others caused on the occasion of the threatening eruption of Vesuvius, Janssons speaks, but without indicating the authorities. *Joan. Janssonii Novus Atlas: Amstelodami*, 1649, T. v. *Introd.*, p. 28, Chap. IX., entitled *Variatio magnetis et declinationis.*

[1] *Cf.* C. C., Chap. I and II.

[2] *Cf.* C. C., Chap. VI, p. 42, and Chap. XIII, p. 70.

[3] In a memoir now in press, I have recapitulated and amplified this research. The first part of this work will be seen in the next volume of the *Memorie dell' Accademia Pontificia dei Lincei d' Roma.*

[4] *Cf.* B. B., I Mem. II[a], and C. C., Chap. X, pp. 60–61.

[5] It was indeed he himself who strove to calm the fears of the mariners and the pilots when they perceived the first turning of the needle, which Columbus attributed to the position of the star called *le Guardie*, in the constellation Ursa Minor.

[6] *Cf.* B. B., I and IV; C. C., Chap. III, pp. 21–29.

These same ideas, excluding entirely that of the declination, are contained in this document, as well as in others absolutely genuine, and show from the apocryphal evidence and in two marginal notes in a writing of the sixteenth century, contained only in the manuscript of Leida,[1] that they are lacking, while there are as well seventeen other examples of earlier date, some contemporaneous with Peregrino. I noted, moreover, that in the manuscript of Leida the deviation of 5° east is marked, and afterwards under errata corrected, that of 7½°; now these values of easterly deviation are exactly those which they had in Italy toward the middle of the sixteenth century, the period of the manuscript of Leida.[2] Instead of this, in the second half of the thirteenth century, namely, when the above mentioned *Epistola* was written, the deviation should have been not easterly but westerly, and, moreover, probably greater than that above mentioned, being then in the middle of the forward motion of the period of trisecular variation in Europe.[3] I confirm, then, the same point by the nautical maps that remained at the end of the thirteenth century, and even to the fifteenth, as well as in part of the sixteenth. Indeed, the pilots' directions having been surely constructed by means of the compass, they are all disorientated in the same way, and at nearly the same value, according to the declination which probably existed in the Mediterranean in the first half of the eleventh century,[4] although not known to the navigators or the cartographers.

Thus, singularly it happened, notwithstanding these twofold false guides, that is, through ignorance of the declination, and through the supposed *plane navigation*, the cartographers continued to model their maps according to the primitive type, and the navigators of the Mediterranean accomplished their voyages at that time by coasting.

I have given elsewhere[5] such reasons as seem to me sufficient, and I am moreover supported by the authority of Nonio Nuñez in this opinion, who affirms that in his time also the mariners attributed the aberrations of the needle to *lee way* and to defect in the loadstone. But, however that may be, in face of the evidence which resulted from the mass of facts, and for reasons which demonstrated their ignorance regarding the cosmical phenomenon, it is not worth while arguing[6] that the medieval navigators of the Mediterranean, though passing to successive ports yet had any extended system of navigation, knowing well

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[1] *Catal. Biblioth. Lugdun. Bat. mss. Chimici*, pp. 2–27.

[2] *Cf.* B. B., I, p. 398, etc.; IV, pp. 321–324; C. C., Chap. III, pp. 21–29; IV, pp. 30–31.

[3] To be found in C. C., the diagram, but the declination in the Appendix II, p. 91, which, however, is there placed as errata corrected.

[4] *Cf.* the diagram above cited.

[5] *Cf.* B. B., I., pp. 410–411; C. C., Chap. IX, pp. 44–50. On page 49 instead of west it is corrected to east.

[6] *Cf.* *La Rivista Marittima.* Rome, June, 1893, p. 519. In a coming number of this review I shall answer other points of the critic of my memoir above cited C. C.

that they made no use of the directive nature of the loadstone, even when they were not able to avail themselves of any visible guide. Furthermore only the angular value between the needle and a rhombus datum was noted on the maps when they steered their course by degrees between two consecutive ports.

I show, however, that on a few of the nautical maps of the fifteenth century, and also in some of the sixteenth, there is found noted in some way, in shape of errata, the correction of the declination, if such be called corrections, and various very prominent notes in writing, subsequent to the epoch of the discovery by Christopher Columbus,[1] as well as those which are found in several log books of the Mediterranean, executed at that time and disorientated similarly to them.

A beautiful confirmation of all that I have said concerning the false divergence of the maps caused by the unknown magnetic variation is found in the most ancient reliefs of the coast of the newly discovered continent.[2] Especially in the more central part of this continent, it is seen that these reliefs are greatly turned toward the east, in consequence of a sort of rotation, for any points west and east of north, through the effect of the remarkable western variation which existed in those regions in precisely the first half of the sixteenth century.[3] In contrast with this, the relief maps of the regions of higher latitude in the two Americas, executed probably at a later epoch and with declinations in some measure corrected, show themselves better oriented, as will be readily perceived by a comparative table recently inserted in an important memoir of Prof. Vittore Bellio, entitled *Notizie delle più antiche Carte Geographiche che si trovano in Italia riguardanti l' America.*[4]

I have likewise shown that there is no foundation for the hypothesis expressed by some, that, in the atlas of Andrea Bianco, in 1436, a certain geometrical figure, intended to have a practical effect on the steering of the ship, contained a hint relative to the declination.[5] Moreover, I have put in evidence how the small displacement of the extremity of the fleur-de-lis in a figure illustrating the compass, which is found in the manuscript of a poem, *la Sfera*, attributed to Goro Dati (probably composed in the middle of the fifteenth cen-

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[1] *Cf.* C. C., S., LI and LII, pp. 87, 88, 89, B. B., IV, pp. 329–331.

[2] Persino Giovanni della Cosa, who in 1493 was one of the pilots of Christopher Columbus, and afterwards a sailor in 1499 and in 1509, in his nautical charts places the compass without declination. Such was the prevalence of the old custom.

[3] In the maps of the Mediterranean the change of orientation is from east to west by north, a point perhaps based on a primitive but false eastern declination. (Placed at the end of the corrected errata to Mem. C. C.)

[4] *Cf. La Raccolta Colombiana* already cited. Part IV, Vol. II, Table VIII.

[5] *Cf.* B. B., I, pp. 411–414. C. C., Chap. VIII, pp. 51–55, and in the appendix pp. 87–89.

tury), in the Library of the Arsenal at Paris,[1] shows no knowledge of the declination. Indeed, of this phenomenon there is found no trace in the text; instead of which, one observes in these little, crude designs of the compass, which, under the guise of an illustrative figure, were added by some foreign designer, occurring in about fifty manuscripts which I have consulted, the fleur-de-lis is first coincident with, then slightly turned to the right, and again to the left of the meridian line. Thus, the different rombi of the same rose are variable, and also in a sense opposed one to another. The same errors of design are found also in the figures of the compass, not only on different maps, but also in those of the same maps. Now all this can not be attributed, as is evident, to the oversight of the designer.[2]

Coming more closely to the age of Columbus, I maintain again that to no one else, nor to himself, was the declination known before his first voyage of discovery. The adjustment of the needle in the rose of the compass was certainly made by Columbus on his voyage to Africa in 1473, as his son Fernando[3] relates, but then only in order to check insubordination of the sailors, who otherwise were unwilling to proceed. Perhaps he was not at first able to make the adjustment of the needle to compensate the false indication of the same through the effect of the declination, although this was unknown as a cosmical phenomenon. Indeed, I have shown that not even in this sense can it be admitted that the Marseillais practised from old a system of correction and that from them Columbus could have learned it, as was the opinion of Gelcich,[4] for the testimony of Dechales,[5] upon which he rested, instead of standing in agreement thereto, and for other reasons which he shows, not only does not mean this, but, on the contrary, proves just the opposite.[6] So, not to exclude the above-mentioned interpretation of the fact related by Ferdinand Columbus, it led moreover to the following words of Ferdinand himself, which are contained in the same work, and give *exclusively* to his father, Columbus, the discovery of the declination *on his first voyage*, saying,

[1] *Manuscrits Italien. Hist. et Geogr.* No. 42 in fol. C, 67 recto.

[2] *Cf.* B. B., pp. 319–321. C. C., Chap. VIII, §. 49.

[3] *Cf. Historie della vita e dei fatti di D. Cristoforo Colombo.* (Trad. di Alfonso Ulloa.) Venetia, 1571. Chap. XVII, C. 41, B.

[4] *Cf. L'Enfanzia della scienza nautica* in the *Rivista Marittima.* Rome, 1890, III, p. 152. However, in a monograph in the *Zeitschrift der Wissenschaftlichen Vereine,* Hamburg, 1892, I modify the preceding hypothesis, concluding that "no one is authorized to presuppose the knowledge of the variation prior to Columbus;" nevertheless I hesitate to admit, as I have said above, that the Italian navigators did not in some way perceive the variation passing from the Black Sea to the North Sea. But my memoir being then already through the press I was not able to insert the above-mentioned conclusion of Gelcich, as I should have done.

[5] *Cf.* P. Cl. Franc. Millet Dechales. *Cursus seu mundus mathem.* Lugduni, 1675, II, p. 271.

[6] *Cf. op. cit.*, Chap. IV, c. 8 *v*. C. C., pp. 83–87.

"that no one had known of such a variation until then;"[1] and that, indeed, such a phenomenon was at first unknown to himself as well as to others makes itself apparent, since he told of this same marvel and of his embarrassment in calming the fears of the pilots and sailors when this aberration of the needle first made itself manifest, for until then it was believed by all that it ought to be always invariably directed toward the pole.

Regarding this phenomenon, and afterwards of the other two discoveries of Columbus during that voyage, namely the existence of a line without declination, or *agonic*, and a variation opposed to the first, the admiral perceived its value as a means to indicate better his own position on his return voyage by the application of this principle. Afterwards, by these same criteria and by the Columbian hypothesis, (however arbitrary) that the famous *ray* or agonic line of separation between the Spanish and Portuguese possessions coincides with the astronomical meridian one hundred leagues to the west of the Azores, and that on the one and on the other side of that limit the isogonic lines deviate by certain invariable amounts from the meridian. Whence arose first in the mind of Sebastian Cabot, and afterwards in that of many others,[2] the supposed great secret of determining in such a way the longitude at sea. Until the first half of the seventeenth century this research was continued by some, using moreover with certain advantage the isoclinic lines. Now, all these vain attempts not being begun until after the commencement of the sixteenth century, and not used in the preceding epoch, mark also the time of the Columbian discovery.

To the objection which some one has made because of the discrepancies noted by Columbus between the indications of the Genovese compass and the Flemish, since in this last the correction of the variation was done at Flanders, and hence known there, I have replied at length in Chapters IV and V of my memoir,[3] putting in evidence by means of a schematic figure the absurdity of such gratuitous suppositions.

At the end of Chapter XII and in Appendix III,[4] comparing the date and the testimony of Sebastian Cabot and of Oviedo, as well as that of other illustrious contemporary and neighboring authors,[5] I show that they had no knowledge of the variation at any time prior to the first voyage of Columbus, and that they may not in any way arrogate to themselves this discovery, as appears from their own words.

[1] How important this affirmation may be is shown in B. B., IV, p. 324.

[2] *Cf.* C. C., Chap. XI, pp. 62–64, and in the Appendix, p. 96, note 1.

[3] *Cf.* C. C., pp. 31–35; pp. 36–41.

[4] *Cf.* C. C., pp. 65–69; pp. 95–97.

[5] *Cf.* C. C., Chap. II, p. 19.

Hence, from the mass of all the evidence brought forward, we seem able to conclude that in the ancient physical discoveries there is no one who has in his favor such demonstrative proof of the discovery of the magnetic declination as has Christopher Columbus.[1]

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## 5.—THE COSMICAL RELATIONS MANIFESTED IN THE SIMULTANEOUS DISTURBANCES OF THE SUN, THE AURORA, AND THE TERRESTRIAL MAGNETIC FIELD.

Dr. SELIM LEMSTRÖM.

The earth's dependence on the sun is not confined to receiving heat and light from it daily; other phenomena also give unmistakable evidence of intimate relations.

The wonderful index of the phenomena in the sun which appears in sun spots and their periodic changes has given us a deeper insight into the physical nature of the sun, and our knowledge of the nature of the bodies in the universe has hereby been greatly augmented. Among other things we have learned that our great central luminary is also dependent, even to a high degree on its surroundings.

The merit of having discovered the *double periodicity* of the sun spots must be ascribed to a number of renowned astronomers, but the merit of having noted such periodic changes in phenomena of our earth belongs to Baué, Wolfe, Fritz, and Loomis.

Using Schwab's collections of observations on sun spots from 1685, Wolfe introduced his well known *relative numbers* for their frequency and compared them with the number of the auroras.

Though auroras were noted in olden times (500 A. D.), it has not been thought safe to go back so far in the comparison in order to gain as sure results as possible.

It was, however, Fritz who detected the parallelism between the periods of sun spots and auroras, which was confirmed by Loomis, especially for America. Very soon afterwards the same periodic changes were detected in the magnetic variations.

Using the work of Fritz, Loomis has given a clear account of all these three phenomena, from which their periodic accordance becomes evident.

These relations established, a zealous work was begun to search

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[1] Replying later to this article in *Rivista Marittima*, June, 1893, pp. 518–519, I show how inadmissible the following hypothesis as there put down may be: "The predecessors of Columbus, convinced of the immobility of the poles, were able to confuse its change in right ascension with the turning of the compass to the northeast and to the westward, phenomena which could well comprise in themselves that of the magnetic declination, inasmuch as the rotation of the pole around the pole came in some way to coincide at least on one side with the variation of the compass."

for them in other terrestrial phenomena, especially in the field of meteorology. Meldrum has shown the periodicity of the number of cyclones in the Indian Sea between the tropics and sun spots and the amount of rain. Many other men of science have shown at least the probability of this periodicity in all meteorological phenomena. Among these Köppen must be mentioned, having made his researches in a more thorough manner than others. He arranged the collected observations in groups according to their situation on the surface of the earth and drew out the conclusions from every group separately. He has not, however, gained quite incontestable results, but such as give highly probable evidence of a close connection.

This purpose in general seems now attained through the valuable work of Prof. Frank H. Bigelow. Through a new method, applied to all meteorological phenomena, he has shown that a closer connection exists not only between the periods of auroras and magnetic variations and the periods of sun spots, but he has also given full evidence of the existence of equal corresponding periods in the meteorological phenomena, and shown the parallelism between them and the periods of sun spots and their dependence on the sun's rotation. From a knowledge more or less uncertain the full evidence has been brought before us through these long and arduous researches.

The yearly yield of agriculture may be considered as a general result of meteorological circumstances. Successful attempts have been made to trace the periodic alterations therein, and such fluctuations reign no doubt in the tropics, but they are also detected in the temperate zones, at least in those parts which adjoin the cold zone.

In all these phenomena a double period is ruling—a longer, of about fifty-six years, and within that five undulations of about eleven years, and also, through Professor Bigelow's results, a short period, equal to the time of the sun's rotation.

The question is, however, more complex than it seems at first. Research on the frequency of auroras in northern latitudes has given the result that they occur in a belt about the North Pole, where their number attains a maximum. This belt is called the polar-light belt, and within it the periodicity is not with certainty perceived. The supposition was early made that the alterations in the yearly number of auroras might depend on a change in the limits of this belt.

This has been indeed verified, particularly by observations in Greenland, in a surprising manner, and we must allow that the periodicity of the auroras in a great measure is caused by the wandering from north to south, and *vice versa*, of the limits of the belt.

Besides the peculiarities now mentioned, certain magnetic disturbances have been found to occur *simultaneously* with the outburst of hot, glowing gas from the sun, which precedes a sun spot.

Carrington made the first observations in this way, and since then

such a simultaneous occurrence has been noticed many times. This fact seems to confirm, at least in many cases, a direct and intimate relation between them. A theory which claims to embrace all the phenomena connected with the appearance of sun spots must, therefore, take this circumstance into consideration and show how it may be explained.

In studying the causes of magnetic disturbances or the irregular phenomena which appear in violent and often relatively great changes in the magnetic force of the earth or of its magnetic field, due attention has not been given to the telluric currents or the electric currents in the earth, and still less to those in the atmosphere. The cause of it was first ignorance of the existence of these currents; yet long and persevering researches have led not only to observing and measuring them, but also to the probability of their being the principal cause, at least in most cases, of magnetic disturbances. Supposing that we reduce all the observations of the earth current to two principal directions, to magnetic north and south and to east and west, we will find the intensity of them and the magnetic storms to agree in the following manner: Increasing north and south current, increasing west declination; and increasing east and west current, increasing horizontal magnetic force.

The degree of agreement is such that their parallel course is unmistakable. By researches in Finnish Lapland, 1871 and 1882–'83, in two localities, in a different latitude each time, the probability of the existence of an earth-current belt analogous with the polar-light belt is brought out. An important fact must, however, be noticed; the variations of earth currents precede the magnetic storms by a certain time not yet surely determined.

Concerning the periodic appearance of auroras, attention must be called to the short periods. Besides the afore-mentioned, we have to remember a yearly and daily period, and also one of about twenty-seven days, the existence of which, being observed before, has been ascertained by recent investigations, especially by Professor Bigelow.

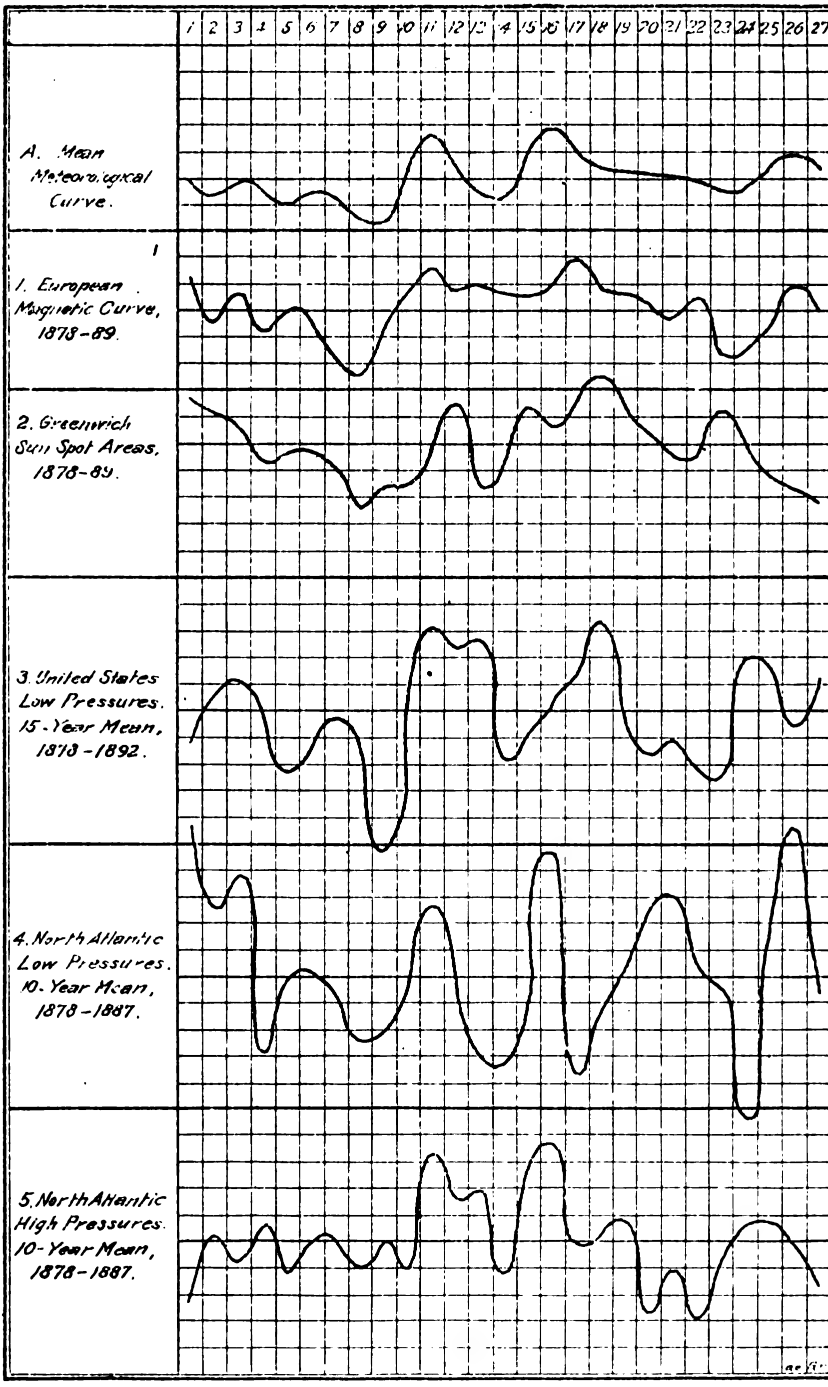
In such a way we find that the experience has slowly been gained, that without doubt all meteorologic and magnetic phenomena more or less closely follow the same periodic changes as the sun spots.

The first question to answer is: Are sun spots the cause of this periodic variation, or is there some phenomenon in the universe, which exercises an effect on the sun and planets at the same time?

The dominating position of the sun in our planetary system tempts us to answer the first part of this question in the affirmative, *i. e.*, to find the causes for every change on earth in the sun, and there, especially in sun spots; but we have to remember that our argument

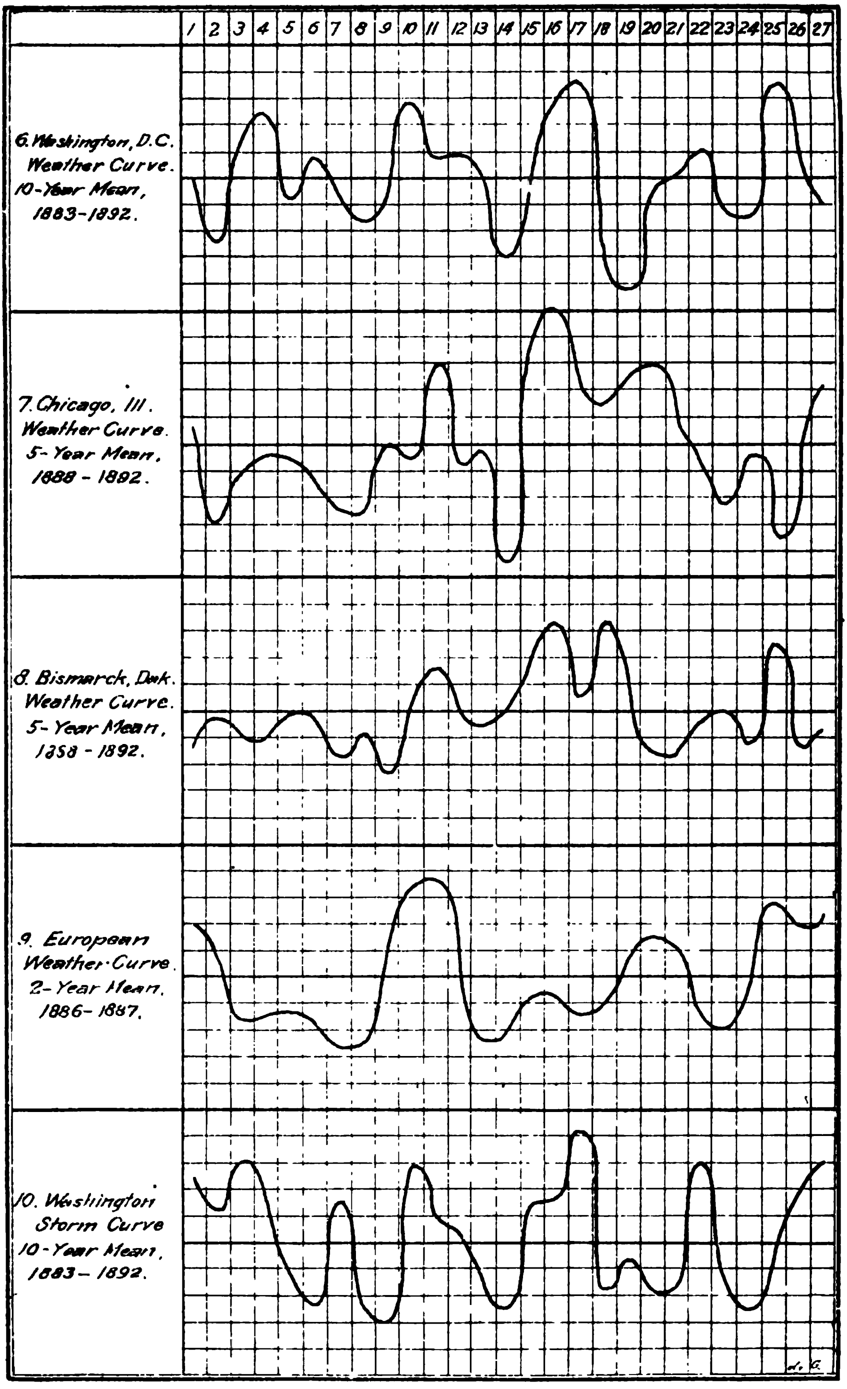
## CURVES IN THE 26.68 DAY PERIOD.

Plate XVI. Bigelow.



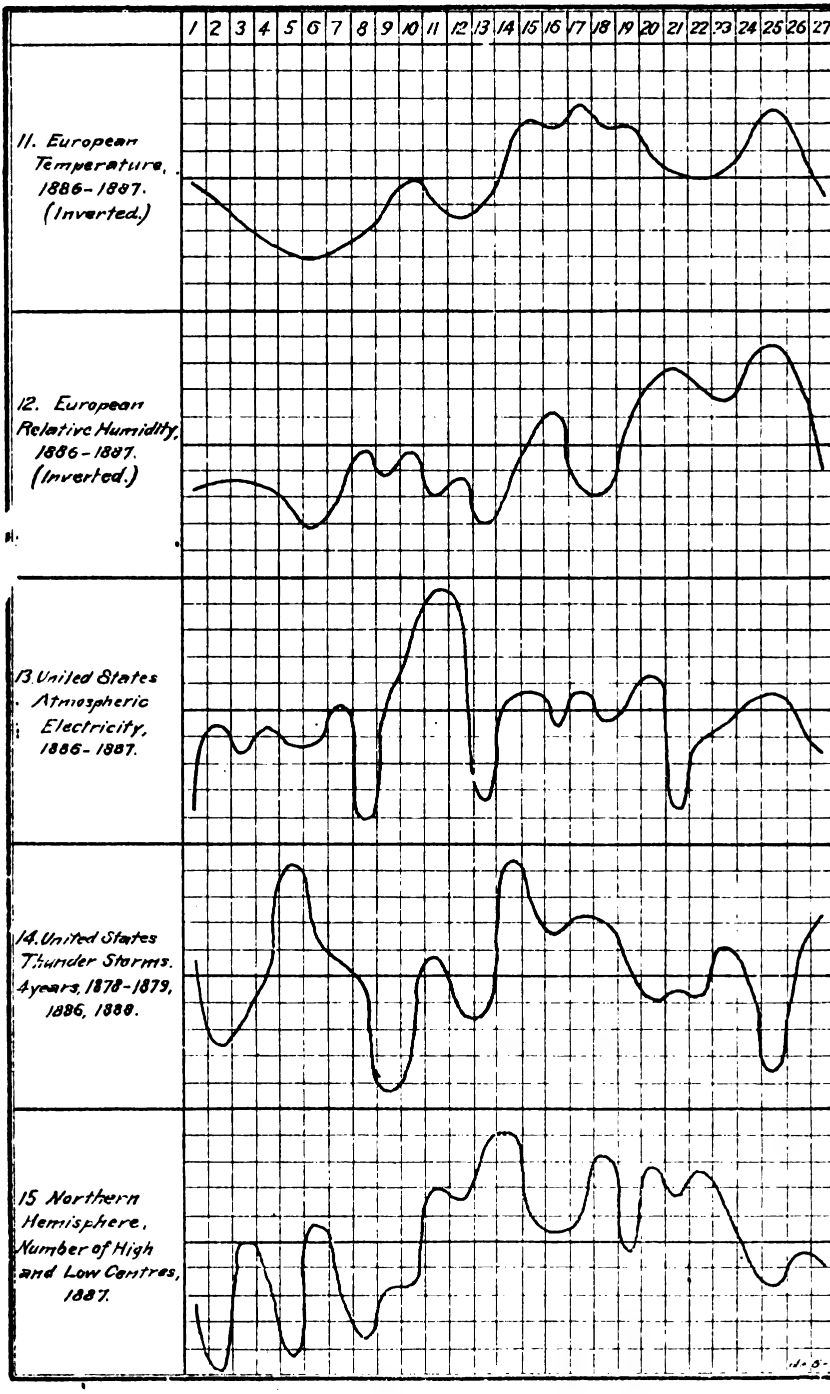
# CURVES IN THE 26.68 DAY PERIOD.

Plate XVII. **Bigelow.**



## CURVES IN THE 26.68 DAY PERIOD.

**Plate XVIII.** *Bigelow.*



is a weak one, and that we, finally, have to let the known phenomena themselves decide if it be possible.

In what manner do sun spots influence phenomena on the earth? The earth receives light and heat from the sun, but we do not know that these phenomena are submitted to periodic changes with the sun spots, and if such changes were known, we do not find in their parallel variations a direct explanation of all the other periodic changes.

We must, therefore, look for other qualities in the sun, which may suffer changes at the same time as the sun spots appear. Is the sun a magnetic body? is our first question. Considering the great heat of the sun, this question must be answered negatively. Every body known to us loses its magnetic quality when heated to a sufficient temperature, but lower than the sun's. It would be very strange if the elements of which the sun consists were to follow different laws, or regain in a higher temperature the magnetism lost in the lower. We must, therefore, give up this supposition, having other reasons besides to do it. As early as 1863, Chambers showed us that daily variations in the earth's magnetism could not be explained by magnetic influence of the sun, and Thomson affirmed it.

After that Lord Kelvin (Thomson) proved that magnetic storms could not have their cause in a direct magnetic influence of the sun, because they require such a great quantity of energy that it would presuppose a total subversion of the whole energy system of the sun. The opinion of a direct magnetic influence must thus be surrendered, and the causes be looked for elsewhere.

Is the sun electric, or does it emit electric energy? We have no reason to contradict the existence of electricity in the sun, and must admit that here electrification is even probable, but of its quantity we have not the slightest notion.

The electric phenomena on the earth, which are of such qualities that their dependence on the sun spots is evident, attain often a magnitude comparable with the magnetic disturbances. If we are allowed to make conclusions from analogy with magnetism, we must arrive at the fact that a direct electric influence can not be the principal cause of the disturbances in electric and magnetic phenomena on the earth.

The modern researches have shown that electric inductive power is propagated in waves with the speed of light, but even looking through this newly-opened window of Hertz into nature's innermost driving power, we can not for the present be enlightened on the question before us.

We have, therefore, to search for the explanation in another manner. Of the quantity of heat the earth receives from the sun, only a part reaches the earth's surface, the rest is absorbed by the atmos-

phere. This absorption is not equal for all kinds of rays. The darker these rays are the more they are absorbed on their way through the atmosphere. The quantity of heat retained in the atmosphere becomes hereby, in a high degree, dependent on the quality of the rays of heat received by it. If the sun's energy should always be of the same quality the distribution of heat between the atmosphere and the earth's surface would also be unchanged. The sun spots tell us now that that can not be the case.

Hitherto we have had no reason whatever to suppose an alteration of the whole quantity of energy from the sun, but its quality is subject to a change. At sun-spot maxima the number of dark rays of heat must be greater than at sun-spot minima, and in consequence the absorption in the atmosphere at sun-spot maxima must be greater, and also the quantity of heat retained in the atmosphere. The variation of the number of dark rays in the solar energy produces also a different distribution of heat between the earth's surface and the atmosphere.

This is a natural law that can not be contested, but the question now is as follows: Are these variations in the distribution of heat between the surface of the earth and the atmosphere so great that they may be considered as the cause of the dominating influence of sun spots? At first we are induced to answer in the negative if looking superficially, but on going deeper into the phenomenon itself we will find that its influence on the atmosphere becomes quite perceptible.

A bright sun without sun spots would send the earth a quantity of heat $= 1$; $\frac{1}{n}$ part of it is absorbed in the atmosphere and $1 - \frac{1}{n} = \frac{n-1}{n}$ reaches the earth's surface.

A sun covered with spots would send the earth in general the same quantity, 1; but $\frac{1}{m}$ is now absorbed in the atmosphere and the rest or $1 - \frac{1}{m} = \frac{m-1}{m}$ will reach the earth's surface.

The proportion $\frac{m}{n} < 1$ is nearly all we know with certainty about its quantity.

It is in harmony with the whole sun-spot phenomena to suppose that not only the spotted area of the sun emits darker rays, but that the whole surface of our luminary in times of maximum of spots emits such rays, and here is still a good field for investigation. The small emissive power of the atmosphere will, to a certain extent, help in retaining the absorbed dark rays of heat. What is now the effect of this variable absorption?

When the spotted area of the sun is lessened a greater quantity of heat reaches the earth's surface and penetrates it, causing an augmen-

tation of its temperature and increasing evaporation. The atmosphere just above the surface of the earth becomes more humid, as its amount of heat is smaller, less water in the form of vapor is retained, and the amount of rain is lessened, but the amount of dew and fog will increase. When the spotted area of the sun is extended the temperature of the ground near the earth's surface will lessen and also the evaporation. The amount of moisture in the atmosphere will be smaller, but considering the greater amount of heat a larger quantity of vapor is retained in it. The condensation of it, if the ruling circumstances are favorable, causes an increasing of the average amount of rain.

In all this it seems as if the influence of the growth of evaporation was not the main point, but the keeping of water in form of vapor within the atmosphere. These consequences are valid, especially for the tropics, where the solar heat is most intense; in other parts of the earth, where the sun's action is less intense, the effect will be more indirect, increasing in an inverse proportion to the sun's direct influence. The greater quantity of water vapor contained uncondensed in the atmosphere is transported through the air currents to higher latitudes, where its immense heat quantities are left.

Hereby arises the remarkable condition, that at the times of sun-spot minima the heat of the earth near its surface must be greater than at maxima, and that at sun-spot maxima the store of heat in the atmosphere will be greater over all parts of the earth, but it will be more perceptible the nearer they are situated to the polar regions. Professor Bigelow's results agree with this in such a way that the curve for the temperature is the inverse of the sun-spot curve.

If we regard only the states of heat, the maxima of sun spots must be more favorable the more we remove from the tropics. Thorough researches in this way have not yet been made, but a large part of the matter before us indicates it almost certainly. As a striking example, may be mentioned a research of the harvest states in Finland, with the following results:

In the year 1696, the epoch of a strongly marked minimum of sun spots, this land, as also the whole of Scandinavia, suffered a drought which brought along with it a terrible famine. The years near 1754 were much harder, and also brought distress to the country here and there, but it was not so severe as the preceding, and it is remarkable that the minimum of sun spots at the same time was not so marked. In the years 1810–'12 the hard times arrived with snow, and in 1867, with a particularly bad growth damaged by night frost, there were caused famine and other disasters. At the last two epochs the sun-spot minima were strongly marked.

Between 1810 and 1867 the records permit us to follow all the

yearly changes of harvests, which hardly can be the case in the seventeenth and eighteenth centuries, because of the lack of observations.

Five undulations are well marked with minima in the years 1810, 1821, 1833, 1845, 1856, and 1857 (see Plate xv). The curves representing the extent of harvest show in an unmistakable manner the same character as the curves for the sun spots, *i. e.*, they are rising from six to seven years and falling during the five or four following years. Further details must here be omitted.

We must at least conclude from all this that the question needs further investigation, and we may here express the hope that any contradictions which are involved in the proposed solution of this problem may be explained.

The difference in the distribution of heat between the atmosphere and the earth's surface must always be a source of change in the electrical condition of the earth in general, and particularly of the atmosphere.

The electricity in the atmosphere is a phenomenon as important in its consequences as the earth's magnetism, and as this latter certainly has its origin in the rotation and revolution of our planet, so the former must arise from some other great phenomenon, and we have no other to compare with evaporation from the earth's surface, and particularly from the oceans.

I know very well all the objections, based on small and uncertain experiments, which are urged against this opinion, but for my part I am an adherent of the theory of my master and teacher, Edlund, in looking for the cause of atmospheric electricity in the unipolar induction of the rotating earth as an electro-magnet, and its influence on the evaporated water in the air.

The distribution of the electricity on the earth depends on the following circumstances:

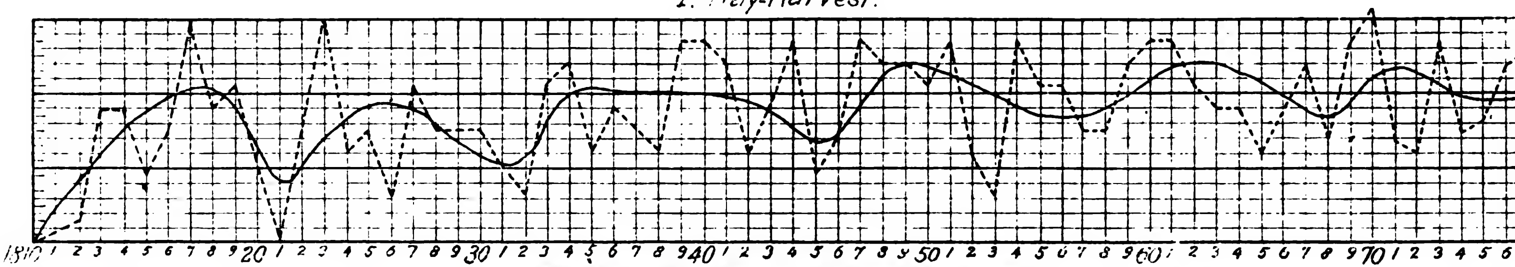
The earth consists of a system of two conductors, the earth's surface surrounded by the air conductor. This consists of a layer of rarefied air, the conducting power of which attains a maximum at a pressure of about 4 millimeters, being a comparatively good conductor of electricity. In consequence of the lower temperature in the polar regions, this upper atmospheric conductor is nearer the earth's surface than in the equatorial regions, and hence it follows that the electricity on it must be slowly streaming toward the poles. Before reaching this limit, the attracting forces between the earth's negative electricity and the positive air conductors attain such a value that they overcome the resistance of the lower layers of the atmosphere and begin to move toward the earth's surface. This happens generally in the auroral belt, but even in other regions situated as well southward as northward. This electric current directed through the earth's magnetism is manifested to us in the auroral

**Plate XV.**

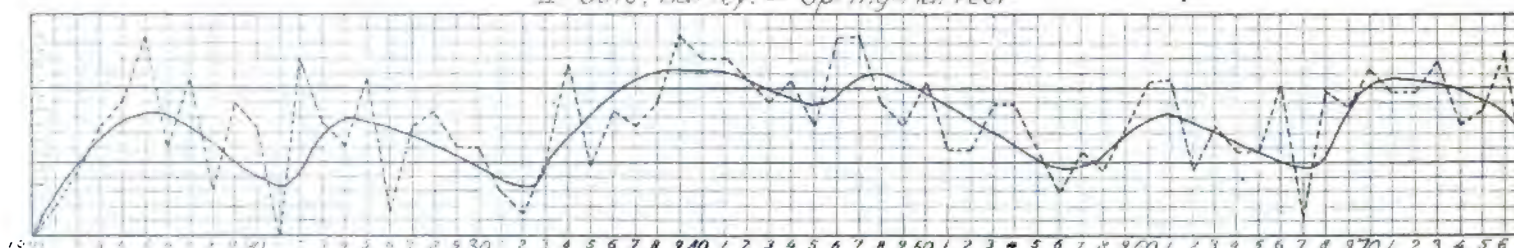
# ANNUAL GROWTH IN WASA AND KUOPIO—1810–1877.

*Lemström.*

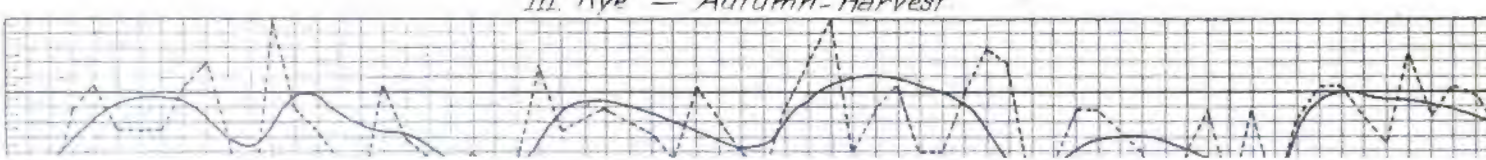
I. Hay-Harvest.



II. Oats, Barley. — Spring-Harvest



III. Rye — Autumn-Harvest



displays, but it is also most probably continuous with variable strength and without producing light.

Coming to the earth's surface, the electricity disturbs the electric equilibrium on it, and hence produces earth currents which, in their influence on the magnetic system of the earth, produce the magnetic disturbances. It is entirely natural that the exercising of such influence will take time. In regarding the great mass of the earth, time can accomplish all that we, from laboratory experiments, can expect. In this circumstance we find the explanation of the somewhat surprising fact that the variations in the earth currents anticipate the disturbances in the magnetic system of the earth.

Here we have the great outlines of the electric and magnetic systems of the earth. This theory, however, does not explain the intimate dependence which is expressed in the simultaneous outburst of a sun spot and a magnetic disturbance.

We have conceded the sun to be electric or electrified, and if we can not concede a direct electric effect of such magnitude as to cause electric phenomena of importance, we can very well conceive an influence of smaller effect acting as an initiatory force.

In papers recently published, Prof. Bigelow has decided upon the existence of a certain electric stress between the sun and the earth, going out from the solar corona. It is now very likely that an outburst of glowing gas in the sun can disturb this stress in such a degree that its effect becomes perceptible on the earth, causing, for instance, an auroral display. We suppose that both conductors of the earth (the surface and air conductor) are charged almost to the point of overcoming the resistance between them, a little change in the force from the sun, an electric force wave, would be enough to cause a final display, *i. e.*, an electric current in the atmosphere, and this will have, at least sometimes, a direct influence on the magnetic needle, but reaching the surface of the earth, it will be the cause of telluric currents, which, in turn, will be the cause of larger magnetic disturbances.

A closer examination of the questions treated above leads to the following conclusions:

The most important question, independent of theoretical opinions, seems to be that the sun's influence, magnetic or electric, is direct or exerted through an unequal absorption of solar energy in the atmosphere according to the greater or lesser number of spots. Regarding the particular relations between the earth currents and the magnetic disturbances a close investigation of the former ought to produce such good results that we may dare to expect real progress in solving the present question. Because a part of the magnetic disturbances are caused through direct effect of electric currents in the atmosphere on the magnetic instruments, it seems necessary to make them an ob-

ject of thorough investigation at the same time. The researches hitherto made into atmospheric electricity can not give us a true knowledge of this current, which does not necessarily produce any change whatever in the potential near the surface of the earth. It has been regarded as a proof against the electric origin of the aurora, that no perceptible changes in this potential are observed during a display, but such an opinion seems to be thoroughly wrong. As the downward electric current can always spread over the earth's surface, it need not cause a perceptible change in the observed potential, which, therefore, may be nearly constant, but on the contrary researches of the force causing this electric current, or the potential in different altitudes will certainly lead to the desired results. Considering the signification of sun spots for pure meteorological phenomena, it seems that such researches must bring about data important for the true understanding of these phenomena, and also probably lead to results which are of use in weather forecasting, regarding the great sensitiveness of the electric phenomena.

Researches of earth currents in connection with observations of the magnetic disturbances and the electric currents in the atmosphere ought, therefore, to receive particular attention. The greater the number of places on the earth in which such observations are made the more extensive and important will the results be.

Concerning the methods for these researches I will, as soon as possible, give an account of those which were used in similar observations at Sodankylä, Finland's international polar station, 1882–'84, and submit them to a thorough discussion.

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## 6.—THE PERIODIC TERMS IN METEOROLOGY DUE TO THE ROTATION OF THE SUN ON ITS AXIS.

Prof. Frank H. Bigelow.

By the permission of the Chief of the United States Weather Bureau, it is my privilege to make a brief statement of some of the results of an investigation, which has been going on, into the action of the sun on the meteorological elements of the atmosphere. In Bulletin No. 2, United States Weather Bureau, 1892, on "A new Method for the Discussion of Magnetic Observations," not only the method of treating the observations was described, but also an outline of the theory of the general work was rapidly sketched. At that time the outcome was clearly seen along one of the main lines of advance, but the end to be attained along the other line was still in the dark. It is possible now, however, to make a number of definite statements that are of importance in the development of meteorology.

The investigation was originally undertaken as a subject in physi-

cal astronomy, but it was soon perceived that its completion involved certain terms in terrestrial magnetism, and also in meteorology. There was a fair reason to hope that along these lines might be found some of the functions, for lack of which solar and terrestrial physics could not be reduced to an intelligible, comprehensive theory. The statements of Bulletin No. 2 have been supplemented by a paper for the astronomical section of the Congress Auxiliary of the World's Fair, Chicago, and in order to gain space for the needed material, the substance of those two papers will be mentioned in the most summary way.

The sun is apparently organized with a nucleus and a concentric shell. The nucleus approaches a rigid condition, or at least one of high viscosity, so that changes within it proceed leisurely. It is in a physical state of polarization, and emits a magnetic field, which puts the surrounding ether in a state of strain, its strength at the distance of the earth being about 0.000115 dyne C. G. S., and therefore capable of direct composition with lines of force from the earth's permanent magnetic field. Thence it is computed that the magnetization of the sun is about 269 dynes, nearly one-fifth that of the maximum magnetization of steel, 1,390 dynes, though in the case of the most intense magnetic storms, this may rise to ten times that of steel, the usual magnetic perturbation being only four or five times the normal, and therefore about equal to steel. This field at the earth has a synodic rotation in 26.68 days, from which the probable error is not 0.005 day; it has been traced day by day for seven European stations throughout the years 1878 to 1889, inclusive, and hence the question of the direct magnetic action of the sun on the earth is answered affirmatively. From computations on the stream lines of the solar corona, and from the variations of the magnetic field at the earth, the distribution of magnetism on the sun can be computed by the harmonic analysis, and its entire magnetic topography made out. This is a work that it has not yet been possible to commence in detail. It is, however, already known that the poles of magnetization of the sun's nucleus, which I call coronal poles, are located about 4½° from the axis of rotation, and that the south precedes the north coronal pole by about 102° of longitude. The north pole is probably the positive, and the south pole is probably a little the stronger. The visible coronal stream lines are certain lines of force of this field, rendered visible like an aurora by peculiar physical conditions. The bases of these lines are confined to two narrow belts about 15° wide, one in each hemisphere, whose mean angular distance from the magnetic poles is not far from 34°. The sun spots are in some way associated with, if not the direct product of this magnetic system, and have local habitats on the sun, the greater number occurring under the meridians of increased magnetic intens-

ity. The period of rotation of the polar regions of the sun, as derived from the magnetic field, is the same as that of the equatorial belt as deduced from the sun spots, and gives the daily mean motion 868.7′ in arc. Hence, it is concluded that the so-called acceleration of the solar equatorial belt relatively to the sun spots in mid-latitudes should really be explained by an antirotational drift or surface current like the westerly trades in the tropics of the earth. In accordance with recent theories, it is supposed that the magnetic lines of force surrounding the sun are rotational vortices in the ether, by whose pressures they are propagated in wide sweeping curves to the earth, and that they therefore enter the polar regions of the earth by the laws of magnetic conduction.

The photosphere of the sun seems to be the seat of another magnetic field, namely, the electro-magnetic field, which Maxwell has regarded as the true source of luminous vibrations. These ether waves arise in the atomic vibrations of the material of the photosphere; are propagated in straight lines in an electric and a magnetic wave in quadrature to the surface of the atmosphere. In passing through these rare gases a series of transformations of the impressed energy takes place in the constituents of the air by which the wave lengths are in part increased with diminution of the amplitude, and also is produced Joule's heat from the work absorbed by the resisting atoms and the static electricity of the atmosphere. (See Poincaré, *Electricité et Optique*, p. 69, Part II.) Thence, I conclude that atmospheric absorption of these impressed rays is one of the most urgent problems in science, especially in its relations to temperature; that the ether waves of induction beyond the limits of the visible spectrum must fully be accounted for, especially in their biological and physiological actions; and it has been attempted to show that the static electricity of the atmosphere is derived from the transformed energy of the ether waves. Accompanying the transmitted waves of the ether is a magnetic wave with a lag of 90° behind the electric displacement, which is of so great frequency as to constitute a steady, uniform magnetic field of force, called the *radiant field*, and acts upon the forces of the terrestrial magnetic field immersed within it. In order to trace out the distribution of this radiant field, whose lines are disturbed by the earth as a magnetic conductor, computations have been made on the observations of thirty magnetic stations distributed over the earth, and the results transferred to a 30-inch model globe. This shows that the uniform field is inflected and exflected at the surface of the earth in a very complex system of forces, but that the law of magnetic refraction is common to them all, the index being about 1.40 and the strength of the uniform field about 0.000125 dyne C. G. S., or a little greater than the coronal field at the earth. Further description of this system of forces must be omitted, but it

appears to be a complete explanation of the observed phenomena of the variations of the freely suspended magnetic needle in its diurnal and annual excursions. Extensive computations on the forces of magnetic disturbances show that they come to the earth on the lines of the coronal field, enter into composition with the complex system of the radiant field and the lines of force of the permanent field, the resultant being that which is recorded in magnetic observations at any instant of time. The auroral displays are physical products of the induced vibrations of these three fields of magnetic force, which have certain habitats in conformity with the distribution of these lines of force, obedient to the laws of magnetic induction. The visibility depends much upon the local constituents of the atmosphere, especially the aqueous vapor, that take up the resultant ether vibrations. The complete mathematical solution of these magnetic functions has not been performed successfully up to this time, as it involves the use of so many variables derived from the astronomical and magnetic conditions as to render the analytic equations very complex.

One must carefully bear in mind the fact that along these two solar fields there come to the earth two distinctly different types of ether vibrations, those of the radiant field being alternating linear displacements and those of the coronal field being rotational or vortical. They form two sources of impressed energy of fundamentally different types, and their transformation and disintegration in the atmosphere gives the basis of some observed meteorological phenomena. It will be necessary to return to this distinction after the important facts regarding the coronal field at the earth have been sufficiently enumerated.

The form of the periodic curve which represents the variations in intensity of the coronal magnetic field, as a system of deflecting forces impressed upon the normal terrestrial magnetic field, was determined as follows: The magnetic observations give hourly readings of the three components of the horizontal force (positive north), declination (positive west), and vertical force (positive inward), and the daily mean of these, relatively to the mean annual values as determined from the means by months, gives a set of residuals in rectangular coordinates. When these are transformed into equivalent polar coordinates, $\varsigma =$ total force, $\sigma =$ horizontal component, $\alpha =$ vertical angle, and $\beta =$ azimuth angle, and collected together, there is manifested a series of periodic changes. This work has been executed for five European stations from 1878 to 1889, inclusive, Greenwich, Vienna, Prague, Pawlowsk, Tiflis, with Paris and Pola added from 1886 to 1889, and also Los Angeles, Toronto, Zi-ka-wei and Batavia for 1887. The changes in azimuth $\beta$ are most striking. All these stations, covering practically the Northern Hemisphere and extending over a sun

spot 11-year cycle, are simultaneously affected by the same impressed forces, so that on given dates for a block of about eight days the azimuth direction is, for example, south along the meridians, and then within a given twenty-four hours the directions in azimuth are simultaneously reversed to the north, where they remain for another longer block of days, as for instance, nineteen.

These peculiar reversals of azimuth were found to recur at very regular intervals of nearly twenty-seven days, so that a direct connection with synodic solar rotations suggested itself. On reducing the 8-day and the 19-day intervals to degrees, it was found that the same interval occurred as already found from the photographs of the corona between the south and the north poles on the sun. Selecting, therefore, the beginning of the short interval as that time when the south pole of the sun's magnetic system is nearest the earth, a series of computations, including four independent least square solutions, namely, for the 3d, 11th, 17th, and 22d days of the period, and embracing the twelve years, gave the epoch June 12–22, 1887, and the synodic period 26.67928 days $= 26^d\ 16^h\ 18^m\ 9.8^s$, or the equivalent sidereal period 24.86319 days $= 24^d\ 20^h\ 42^m\ 59.6^s$. From these data a magnetic ephemeris was constructed from 1875 to 1900, giving the dates of the recurrence of the passage of the south coronal pole of the sun past the earth. This period has been tested in so many ways, and responds to all demands upon it so faithfully, that I have no hesitation in saying that it is the natural period to be adopted in magnetical and in meteorological computations. It should, therefore, entirely supersede the use of the calendar month, as a period for taking residuals with reference to a mean, because the calendar month has no reference to periodic recurrences of these phenomena, and therefore the residuals cut themselves up in applying to a long series of observations. This successful localization of the recurrent effects with reference to certain meridians on the sun, fulfills a long-felt need in physics, and will enable us to classify the heterogenous mass of residuals in these subjects that have hitherto defied examination, and will also hasten on the process of elimination of the different systems of forces acting on the earth, and a separation into their appropriate parts. Thus, there now may be found terms depending upon the diurnal rotation of the earth on its axis, the annual motion of the earth in its orbit, and the solar rotation of 26.68, which exhaust all the astronomical periods proper. I have found the use of this period so helpful in the study of meteorological phenomena that its adoption in general can not be too strongly recommended. The remainder of this paper will be for the most part devoted to illustrating the application of the coronal period to the phenomena under consideration.

In interpreting the resulting curves, some reservations must be borne in mind. Whatever may be the mean magnetic system existing

on the sun, it is evident that it is not at all times in a steady, quiet condition, but is constantly undergoing fluctuations, as can be assumed from the behavior of the spots in the 11-year period, the local outbursts of the prominences, the faculæ, the terrestrial magnetic storms, and the auroras. Until this line of research has been cultivated much more perfectly than at present, so as to understand the meaning of such peculiarities, only approximate reproductions of the normal mean curve will be obtained at any time. This same inexact repetition of the periodic intensity, as, for example, when the maximum occurs on one or the other of the possible maximum points of the curve for a given passage along the curve, or when the outburst occurs a day early or late as referred to the mean, diminishes the surviving amplitudes after a long series. Therefore, at the end of several years, it is found that the residuals are much cut down from their primary values, although the true relative changes reappear on restoring the amplitude of the residuals by a proper factor. Furthermore, in any actually observed phenomenon in meteorology, we can not have what is desired distinctly separated from all other sources of energy. Thus, in barometric pressures, the radiant field at the equator distributes its energy through the system of highs and lows due to the rotation of the earth on its axis, which, though called permanent, are under constant flux locally, in accordance with the prevailing thermodynamic conditions, so that whatever pressure may be due to the coronal magnetic field, it is always masked by these conditions. In spite of these difficulties arising on the sun and on the earth, the following curves are without doubt instructive, and all tend to prove the effectiveness of this magnetic action upon the atmosphere of the earth:

1. The magnetic curve for the European stations during the twelve years, 1878–'89, is obtained from the residuals of the horizontal component $\sigma$ and the individual periods within each year being separately computed, the annual curve for each year and the mean for twelve years taken, and the latter here reproduced. Units = 0.000001 dyne C. G. S. It shows crests on the 3d, 6th, 11th, 13th, 17th, 22d, and 26th days, the prominent maxima being on the 3d, 11th, 17th, and 22d days, this subdivision forming the real basis of the six and seven day cycles that have so often been noted. It will be observed that the mean curve has one long sweep with minimum on the 7th and maximum on the 17th, with a secondary minimum on the 24th and maximum at the beginning of the period. This makes the genera curve drop at each end relatively to the center; the intervals 3d–11th days and the 22d–26th are those conspicuously brought out in the system of azimuth reversals. This subject is very extensive, but no more can be stated here.

2. The sun-spot areas in millionths of the sun's visible surface, as given in the Greenwich volumes, were collected by periods, by annual means, and by the 12-year mean, the latter being here given. The reducing factor is used so as to make the amplitudes about the same. The general sweep of the magnetic curve and the crests occur with approximate accuracy, though it is suggested that the sun-spot curve lags a little, as if the spots were secondary effects of the outpouring of the magnetic system, or else have drifted in an antirotational direction. The localization of the spots on solar meridians is clearly seen.

3. The United States Weather Maps for fifteen years, from 1878–'92, were examined, and the minimum pressures for the day, the mean of two or three readings, tabulated in units of hundredths of an inch, the final mean being here copied. The separate years show more or less conformity to the fundamental curve, and the result is that the low pressure troughs rise and fall in relative depth with the change in magnetic force of the field.

4. The North Atlantic low pressures for the ten years from 1878–'87 were taken from the International and the Hóffmeyer Synoptic Charts, and were tabulated in accordance with the coronal period. A remarkable feature is that this curve must be inverted in order to agree with the magnetic curve in direction, which indicates that the permanent North Atlantic "Low" varies inversely with the strength of the field. Such inversion appears here and there among the meteorological data, and leads to many important and curious consequences. In this case the conclusion is quite evident that the strengthening of the magnetic polar field increases the general atmospheric circulation all over the hemisphere in the channels marked out by the continents and oceans and the rotation of the earth.

5. The North Atlantic high pressures of the permanent anticyclone show the same direct variations with the magnetic field as the United States low areas.

6. The intensities of the general weather prevailing day by day, as recorded in the journal, were marked on a scale of 4, where 1 = clear, 2 = partly cloudy or windy, 3 = some precipitation, high winds, 4 = severe storm, and then collected by the period, the plotted numbers being the final residuals multiplied by the factor 2. The Washington curve, with more or less exactness, period by period, shows that the weather fluctuations follow the magnetic system, even when considered at one station. From personal observations of the weather conditions for a year, with the magnetic curve before me, I may report my belief that the two are so intimately associated together as to form a basis for general long-range forecasts. I hope that a complete mastery of the magnetic system, involving a continuous watch upon the condition of the sun's field, will gradually enable us to sepa-

rate the action of the equatorial field and the effect of the rotation of the earth from that of the polar field.

7 and 8. The Chicago and Bismarck curves likewise follow the fundamental type curve.

9. The maps of the German Weather Service were read off by general estimate for the years 1886 and 1887, paying attention to the condition of the whole territory covered. From these results can be deduced the principle that weather conditions vary all over the hemisphere directly with the cosmical magnetic field, and it may not be going too far to say that the field causes part of the intensity of weather phenomena, however much the form of display may be masked by the operation of other causes.

10. The number of 4's (severe storms) occurring on each day of the coronal period for ten years were counted up for Washington, and the variations on the mean reduced to the accompanying curve. It shows that severe weather may be expected near the 3d, 6th, 11th, 17th, 22d, and 26th days of the period rather than anywhere else, and since by means of the ephemeris such dates may be found years in advance, the type of weather that will probably occur may be approximately forecasted at least to this extent. The reading of the changes of the daily weather maps should also be facilitated by the knowledge derived from this intensity curve.

11. The temperature curve is obtained from the same seven stations for which the magnetic computations were made, and it shows that temperature and magnetic intensities vary inversely, since the curve as here plotted is inverted in the signs of the ordinates.

12. The relative humidity curve is computed for the same seven stations for two years, and like the temperature it indicates an inverse variation to that of the magnetic curve. It has not been possible for me to cover the hemisphere with temperature and relative humidity computations, as in the case of pressure, even in such a general way as the one there pursued. Careful and complete treatment of these two elements should be carried out, as the results promise some radically important contributions to theoretical and practical meteorology.

13. The curve for atmospheric electricity was derived from the data in Professor Mendenhall's report of observations conducted for the United States Signal Office, at several stations in 1886 and 1887. It shows that this element varies directly with the magnetic field.

14. The data for the thunderstorm curve were taken from the United States Monthly Weather Review, and are exceedingly rough; for the years 1878–'79 being the number of States reporting, and in 1886–'88, the number of storms reported in all the States. The frequency of these storms varies directly with the intensity of the magnetic field.

15. The number of high and low centers was obtained from the International Weather Charts of 1887, by counting the number of distinct maxima and minima pressures, as shown by the inclosed areas on the map. It declares that the whole hemisphere suffers changes in pressure distribution with variations in the intensities of the magnetic field, that this cosmical force sets the atmosphere of a whole hemisphere into more rapid circulation, by which the number of pressure centers and storms is increased on certain days of the period. This can be seen on the maps when attention is directed to it.

Similar studies of the auroral frequencies—the United States "Highs," the International Polar Stations of 1882–'83, and the Siberian stations for the same years—give harmonious results, though they must be omitted from this abstract. An arrangement of the annual means side by side through the sun-spot cycle, beginning with 1878, shows that the magnetic field and sun spots and the United States "Lows" vary directly, but the North Atlantic "Lows" inversely, in the 11-year cycle.

Passing now from details to generalizations, I think it will be admitted by the most captious critic that there is something in it, how much being still the subject of strict investigation. It will certainly be difficult to overthrow the meaning of the total mass of testimony, which will undoubtedly be strengthened by continued applications of the period to observed phenomena, however much may be desired in regard to the steadiness of the residuals. Let us see what bearing this has upon general meteorology. After a very close study of the mathematical details of the theories as propounded by the American and German schools, it seems to me that something is still lacking between theory and observation. The application of the Eulerian equations of relative motion to the general circulations of the atmosphere has undoubtedly been successful, but the probable fault has been in extending this theory, by analogy, to cyclones and anticyclones. For in order to get a source of energy sufficient for the effects observed, instead of the impressed energy of the radiant field at the equator and the conservation of areas of equal motion, we are told to employ Carnot's cycle of operations for mechanical heat, or secondary motions derived from general currents of the atmosphere. The analogy can only be partially sustained in mathematical details, and in addition to the many practical objections urged by Hann, and others, this one seems very impressive. By the Eulerian theory, "Highs" and "Lows" mutually feed each other, as in the general case of a hemisphere, or else they must cease to exist; but thus they isolate themselves from the general circulation, and form secondary conservative systems within the primary. Now, in practical meteorology, the exchange of air from the equator to the poles, in the high-

flowing northeast currents, is clearly made out, but there is surprisingly little provision made for the return of this air from the pole to the equator along the earth. On the face of the problem, the anticyclone and cyclone would appear to be a mechanism for overcoming the surface friction of the low-flowing antirotational return current. Thus, these may be regarded as a system of double vortex knots, whose free ends lie one in the polar regions and one near the trade belts, both in the upper strata. The circulation should be from the polar strata down through the anticyclone in a reversed helix, then up through the cyclone in another reversed helix, the drainage southeast current feeding the permanent anticyclone of thirty-fifth parallel, whence the trades proceed. The history of the drainage current from the upper cyclone has not yet been well written. This is at present a theory worth considering, and it carries us to vortex wave motions for our mathematics rather than to the hydrodynamic equations of relative motions.

Note the meaning of the magnetic physics that has been outlined. According to current meteorology, an increase in the intensity of the radiant field at the equator gives an increase in hydrostatic pressure, an increase in temperature, a decrease in relative humidity, a decrease in cloudy condensation, and an increase in vapor tension. According to my analysis, an increase in the magnetic polar field gives an increase in pressure, a decrease in temperature, a decrease in relative humidity, a decrease in precipitation, and an increase in cloudiness. Therefore, the radiant or electro-magnetic field is favorable to producing warm, dry, high pressure areas, such as are seen in the permanent tropical belt, while the magnetic polar field is favorable to the production of the cold, dry, high-pressure areas, such as frequent the storm belts farther north. This may be explained physically as follows: The electro-magnetic ether waves are linear vibrations, which increase the frequency of collisions and the length of the paths of excursion of the atoms of the air, and thus the pressure and temperature together. The magnetic ether rotations are circular, tend to widen the atomic orbits, and make them flow more in parallel, thus polarizing them about the lines of the field as axes, and thus increasing the pressure while diminishing the temperature.

Hence it would seem that the coronal magnetic field, by an increase in its intensity over the entire polar cap, tends to build up dry, high-pressure areas, which are then expelled outward hydrostatically, and seeking the warm high pressures near the tropics, by vortex waves and knots, pass through the anticyclonic and cyclonic system in this chain of circulation, whose purpose is to keep the currents off the ground. Thus, precipitation and cloudy condensations are incidents to which the thermodynamic laws properly apply. By this mechanism in air circulation some of the objections alleged against the iso-

lated system of "Highs" and "Lows" are certainly avoided. The power of storms is placed in the highs, and these are more or less rigorously under control of the polar magnetic field, which is absolutely dependent upon the output from the solar nucleus and the rotation on its axis. The amplitude in the range of hydrostatic pressure of the atmosphere in the polar regions is about 6 millimeters in the annual mean, and in Europe about 4 millimeters, even after the residuals have cut themselves down algebraically by the succession of highs and lows produced in the general circulation; in the tropics this field can have no influence.

Such a radical change in meteorological matters must ultimately depend for verification upon long continued treatment of the data of observations, coupled with adequate mathematical analysis. One of the earliest tasks is to obtain the physical functions of each meteorological element in terms of the strength of the magnetic field, but this will require much careful and laborious research. The demands of meteorology would also indicate the necessity of providing for suitable magnetic observations in the United States, alongside of the ordinary meteorological data being so abundantly procured. We are, however, peculiarly deficient in this regard, and can hardly expect to make any progress till the gap has been filled. The analytic problems of the distribution of magnetism in the sun, and the observation of its changes, together with the distortion of the solar fields as they pass the region of the earth, are tasks not only important but fascinating. It is thought that a fair beginning has been made in the analysis and classification of this series of cosmical phenomena, and that future investigations need not be impeded by the general lack of perspective that has so long distorted this beautiful view of the solar system. In order to facilitate a general study of the comparison curves, the mean coronal curve, adopted as a composite from the study of the entire system of variations for fifteen years, is given as curve *A*. By comparing with each curve, one can readily perceive that they form a general system of functions, and that the independent variable to be selected is the intensity of the solar magnetic field.

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## 7.—REVIEW OF RECENT INVESTIGATIONS INTO THE SUBJECT OF ATMOSPHERIC ELECTRICITY.

J. ELSTER and H. GEITEL.

When, one hundred and forty-two years ago, Benjamin Franklin gave the first impulse to that series of bold researches through which the electricity of the air has been added to the domain of our investigations, one might, perhaps, have ventured the prophecy that at the

end of the nineteenth century the problem of atmospheric electricity would be finally solved.

But the investigators of that epoch did not fully realize the difficulty and complexity of it. One ought to remember the names Musschenbroek, Saussure, Volta, in order to understand the great interest and continuous efforts which the direction given in America, toward the end of the eighteenth century, aroused among the leading physicists of the old world.

Although we must acknowledge to-day that we are yet far from a clear insight into the relations of atmospheric electrical phenomena, while in other fields of electrical investigation so much more has been accomplished, we ought to ascribe this retardation in part to a certain cooling of zeal, which, in the first half of this century, followed each brilliant discovery.

The lack of a comprehensive method of measurement, which is exposed in such investigations to a great many disturbances, for an understanding of which the reason had not been given, or was not sufficiently well known, the undeveloped condition of meteorology at that time, the diversion of interest from electrostatic to electro-chemical, electro-magnetic, and induction phenomena, accounts for the diminution in part of the study of atmospheric electricity. But thanks are due to the men who separated from the main body of electricians in a persevering struggle with the hindrances which prevented work in this field. So in Germany Maréchaux and Schübler were able to derive from a rich material some probable conclusions, which, through new observations, are now fully established. Later, in France, Peltier improved upon the method of measurement, and brought to general notice the methods already established by Erman, according to which the so-called fair-weather electricity is due to an inductive influence given forth by the negatively charged body of the earth. About the middle of our century the activity in this field again increased. Lamont in Munich, Quetelet in Brussels, Dellmann in Kreuznach provided for the establishment of independent series of observations, and Lord Kelvin (Sir W. Thomson) improved the electrostatic methods of measurement to a degree which for meteorological purposes can be regarded as more than sufficient. But of yet greater importance is the method, first clearly developed by him, of making measures of atmospheric electricity at different places of the earth comparable with each other, when he introduced as the fundamental measure the difference of potential of two points of the atmosphere which lie above a horizontal plane, in units of vertical distance.[1] Hereby the measure of the electric field of the earth (the potential-

[1] Sir W. Thomson, On Atmospheric Electricity. Proc. Roy. Inst. of Great Brit., Vol. III, 1860, p. 285.

fall) above the earth's surface has been expressed in absolute measure, which also was attempted by Hankel.[1] The value of this idea, although due to him, was not really understood, so that the impulse of Lord Kelvin helped to renew interest in this subject. In England, at Kew, a regular service of observations was installed. Mascart at Paris made of Lord Kelvin's electrometer a self-registering instrument; at Melbourne, Neumayer made observations; at St. Louis, Wislicenus; at Moncalieri, Denza; at Vesuvius, Palmieri. Yet with these the list of stations is not complete. These observers, distributed all over the earth, confirmed the conclusions made in earlier and more restricted regions that the phenomena of atmospheric electricity are very interdependent. Certain regularities exhibited themselves, as the prevalence for the most part of the positive sign of electricity in fair weather, the general agreement of the change in neighboring fair days, and the diminution of the potential from the cool to warm season of the year. But frequently this normal course is interrupted by strong perturbations, variations of more than one hundred times the normal height take place, and even the signs of the potential-fall in the space of a few minutes are not constant. Such phenomena occur regularly in connection with considerable precipitation; in a cloudless sky they are very infrequent.

It is evident that there can be no meaning derived from taking the mean through algebraic addition of such variable values, or to reject all measures from the same, which exceed an arbitrarily determined limit. This difficulty Exner[2] has now overcome by separating the observations of the normal field from those in the disturbed, so that in the first one only includes those which are taken in a fully cloudless sky, which has continued a certain time. Meanwhile, he has learned to reduce the measurements to absolute measure, in the meaning of Lord Kelvin, and to give to them a fixed definition. Falling back upon the principle of the old gold-leaf electroscope, he invented a very important apparatus for observations of atmospheric electricity,[3] which is inferior in accuracy to Mascart's electrometer, but, on account of its adaptability and convenience, is to be accounted as an important improvement in our apparatus.

The division of the whole territory of atmospheric electricity into the two parts of the normal or fair-weather electricity, and the accompanying electrical phenomena of cloud and precipitation, is so important that it may be laid at the basis of the following review of the recent advancement.

[1] W. G. Hankel, *Ueber die Messung der atm. Elektr. in absolutem Maasse.* Abh. der Sä̈ch. Ges. der Wissensch., p. 381; Poggendorff's Annalen, CIII, 1858, p. 209.

[2] F. Exner, *Ueber die Ursachen und Gesetze der atm. Elektr.* Sitzb. Akad., Wien, XCIII, 1886, p. 222.

[3] F. Exner, *Ueber transportable Apparate zur Beobachtung d. atm. Elektr.* Sitzb. Akad., Wien, XCV, 1887, p. 1084.

Before one can attempt to bring electrical measures of cloudless days into connection with other meteorological factors, one must decide the question, how far the variations occurring in the observations are to be treated as general, and how far as only local and accidental; in other words, one must investigate whether, and to what extent, outside of cloudy days, sources of disturbances remain to be considered. The experiments show that this is the case. Dust, snow, and smoke whirled about, as also in a very marked manner the presence of falling and spattering water, works great anomalies, because they produce negative electricity in the air, and so let the potential-fall sink below the normal value, even below zero.

Therefore, observations of fair-weather electricity are lacking in the neighborhood of damp depressions, as well as of smoke and dust, such as are always near great cities, but also those are excluded which are taken near certain places in heavy winds, and also very dry weather or in driving snow. It is, therefore, necessary, in the valuation of electrical measurements to examine critically the conditions of precipitation, without at the same time falling into the error of excluding from them every irregularity as a disturbance. Certainly it is an improvement to diminish the influence of the lower dusty strata of air through the employment of the galvanometer in the method of observation by means of flying kites, as introduced by McAdie[1] at the Blue Hill Observatory, and again taken up by Weber,[2] in Kiel; yet it is questionable whether this advantage is not too dearly bought, through the impossibility of determining the height at which the measures have been made. Therefore, regular observations at the surface of the earth must undoubtedly, for some time, furnish the principal material for atmospheric electrical researches. Furthermore, one must remember that the deduction which was based on an erroneous observation made on the peak of Teneriffe (namely, the deviation from the normal value to a negative potential-fall in clear weather) is contradicted by Abercromby.[3]

If one judges from the disturbances just described, which have their loci at the earth's surface in the neighborhood of the place of observation, it is necessary to consider the question how the fair-weather electricity with its variability is related to the great periodic changes of the atmosphere.

Since regions of precipitation, when they prevail in places of observation, exercise the greatest variation of potential-fall, the conjecture

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[1] A. McAdie, Proc. Amer. Acad. of Arts and Sciences, XXI, 1885, p. 129.

[2] L. Weber, *Mittheilungen betr. die im Auftrage des elektrotechnischen Vereins ausgeführten Untersuchungen über atmosph. Elektr.* Elektrotechnische Zeitschrift, X, 1889, p. 387.

[3] R. Abercromby, The Electrical Condition of the Peak of Teneriffe. Nature, Lond., XXXVII, 1887, p. 31.

arises whether they will also exhibit themselves at great distances from the electrical instruments in a measurable way; that is, whether it will not be possible to employ electrical measurements for forecasts of the weather. This thought was put to the proof for a short time in an extensive series of observations by Mendenhall[1] in the United States. A negative result has been obtained. A decided electrical action at a distance from areas of precipitation, useful for forecasting, was not discovered.[2] One must, therefore, consider the electrical development in the case of precipitation as essentially local, and herein lies an important verification of the author's view, to exclude these in the investigation of normal atmospheric electricity. In considering this, the Erman-Peltier hypothesis is to-day well nigh universally accepted, according to which the earth's surface under ordinary conditions is charged with free negative electricity. Herein lies another expression for the fact that the potential-fall is positive. One can either consider the whole earth as a sphere with a negative charge of its own, as Exner does, or, like Lord Kelvin, can treat the atmosphere as the dielectric of a condenser of which one layer, the earth's surface, is negative, and of which the other at the upper layers of the atmosphere is positively electrified. In each case one considers a variation of the potential-fall at the surface of the earth proportional to the density of the ground electricity. This variability consists in the yearly period, whose maximum falls in winter and minimum in summer, and of the daily variation which is conditioned by the influence of the place of variation and the time of the year. It seems that the daily oscillation is the more regular the higher the sun rises above the horizon at midday at the place of observation; that is, that in temperate and cold climates it is specially discernible in the warmer parts of the year.

According to the numerous results in agreement taken at Kew, Moncalieri, St. Louis, Wolfenbüttel, Ceylon, and other places, the potential-fall diminishes from a maximum in the morning hours during the day to rise again to a second maximum during the evening or night. An agreement was recognized in the year 1858 by Neumayer,[3] and later by Hann,[4] between the daily oscillation of the

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[1] T. C. Mendenhall, Report of Studies of Atmosph. Electr. Memoirs of the National Academy of Sciences, Wash., v. 1889, pp. 113–318.

[2] It appears that the observations have been in part made under the influence of local disturbances. The authors understand that the electrometer at Ithaca, N. Y., was placed not far from a spurting water course, and that from this the frequent negative disturbances result which characterize this station.

[3] G. B. Neumayer, Some Facts Illustrative of the Meteorology of the Month of August. Trans. Phil. Inst. of Victoria, III, 1858, pp. 104–114. [The same.] Discussions of the Meteorological and Magnetic Observations made at the Flagstaff Observatory in Melbourne during 1858–'63. 4°. Mannheim, 1867, p. 78.

[4] J. Hann, *Resultate der meteorol. Beob. der Franz. Polarexpedition*, 1882–'83 *am Cap Horn*. Meteorol. Zeitschrift, VI, 1889, p. 106.

barometer and that of the atmospheric electricity. This was confirmed more recently through an extensive series of observations by Fines at Perpignan,[1] and Andre[2] at Lyons.

One can consider a sinking of the potential at any place to be brought about by supposing that the negatively charged earth's surface gives up a portion of its electricity into the air lying above it. From well known electrical principles the intensity of the electricity must then diminish above that place. In its most general form the idea of the variability of the potential, attributed to a dissipation of the electricity of the ground into the air, was expressed by Linss[3] at Darmstadt; in connection with certain qualifications to be mentioned in that which follows, it was formerly employed by Exner and afterwards by Arrhenius and the authors.

For the explanation of the periodicity one must again introduce the assumption that the electrified masses of the earth are carried through the discharge into the air; otherwise the potential-fall would approach zero along an asymptote. One can distinguish two possibilities: Either the electricity derived from the earth can press up to the limits of the atmosphere and there dissipate itself in space, perhaps also neutralize the positive masses contained in the air, for there is an electro-motive force to be assumed (perhaps even of extra-terrestrial origin, which returns them to the earth in like measure), or they will be held back in the air, and especially in the lower strata, for then the total charge of the earth as a planet is constant, and the question restricts itself to this, how does it happen that the electricity dissipated in the air again reaches the surface of the earth? On account of its simplicity the last possibility offers the best view of the problem, and without wishing to lay aside the first and the consideration of a cosmical source as improbable, we will reckon here with the last. With great unanimity it is assumed that the atmospheric precipitation produces this electrification of the air and recharging of the earth's body. This conclusion has much in its favor, since the investigations of Aitken assume the condensation of vapor in the free air to be dependent upon nuclei, which, according to Nahrwoldt,[4] alone can be the carriers of electric charges in a gaseous body. Above all, it must here be remarked that the group of phenomena collected together under the name of precipitation electricity can not be explained as extending through a simple transportation of negative electrical masses to the earth. We have the

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[1] Bulletin Météorologique du Département des Pyrénées-Orientales, 1888.

[2] André, *Rélation des phénomènes météorol. déduits de leurs variations diurnes et annuelles.* Lyon, 1892.

[3] Linss, *Über einige die Wolken-und Luftelektricität betreffende Probleme.* Meteorol. Zeitschrirt, IV, 1887, p. 345.

[4] Nahrwoldt, *Ueber Luftelektricität. Inaugural Dissertation.* Berlin, 1876.

means to determine directly the presence of negative electricity in the air. It consists in the measurement of the potential-fall at great heights over the earth's surface. The result is the diminution of the same with increase of height.

Observations of this kind, with air balloons, were first made by Exner,[1] and recently by Tuma,[2] which have actually given the expected diminution. But a repetition of this experiment is urgently desired, and especially upon the consideration of the disturbing influences which the balloon exercises on the level surfaces of the electric field of the earth in its neighborhood. Measurements on the peaks of mountains can also serve for the explanation of this question. Generally the absolute values of the potential-fall at such places are not comparable with those on a plain, because the geometrical form of the mountain itself causes an increase in the surface density of the earth's electricity; yet one can determine from the relations of the daily and yearly extremes of the potential-fall the limits between which, at the heights considered, the contents of the air varies in free negative electricity. From collected observations covering a long series by Michie Smith[3] on the Dodabetta in the Neilgherries, India, this is seen, and the authors hope soon to publish a collection of such measurements comprising several years, which have been carried on by the observer of the station on the Sonnblick in the Alps. Hereby the daily and yearly curves of the potential-fall at 3,000 meters will be greatly flattened. The diminution of the contents of the free negative electricity of the air is there much smaller than in the lowlands.

If one thus considers the variability of the potential-fall as due to the dissipation of the electricity of the ground into the air, its daily and yearly variations must be conditioned through an opposite period in the coefficient of dissipation of the atmosphere (Erde-Luft). The question allows itself to be handled purely experimentally, when one measures the loss of electricity which a trial body, enveloped by the free air, suffers in the different yearly and daily seasons. Such measures Linss[4] has undertaken, and has found, as Coulomb did earlier, a period of the dissipation coefficient with the maximum in summer and minimum in winter. Because of their importance, these experiments deserve repetition, employing the best means of insulation, as the quartz fiber of Boys. If this period is determined to be real the course of the potential-fall would be brought to a better understanding. The question remains to be answered,

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[1] F. Exner. See footnote No. 2, p. 512.

[2] J. Tuma, *Luftelektricitätsmessungen im Luftballon.* Sitzb. Akad., Wien, CI, 1892, p. 1556.

[3] M. Smith, Trans. Roy. Soc., Edinburgh, XXXII, p. 583.

[4] Linss. See footnote, p. 515.

what physical property of the air is the cause of the variability of the coefficient of dissipation? Restricting oneself to the electrical dissipation from the ground, which alone comes under consideration, there are two ways of explaining this variability. One, as already remarked, proposed by Exner,[1] proceeds from the assumption that the dissipation follows the evaporation of the water of the earth's surface, because the water vapor itself in leaving the ground carries with it negative electricity into the air. Since herewith the yearly curve of the potential-fall must run somewhat inversely to that of the vapor pressure, which corresponds to the facts, so by means of it the yearly period of the atmospheric electricity is satisfactorily explained. It is thereby possible to express this dependence in a formula, which is well founded in its mean values, upon a very large number of observations in middle Europe and Ceylon. (The last are, on account of the high value of the vapor pressure, especially interesting.) The fault of the Exner theory lies in this, that it does not fully explain the daily period, and that the convection of electricity through water vapor, laid at the basis of it, is not sufficiently founded in experiments.

Differing from Exner, von Bezold[2] and Arrhenius[3] assume a photoelectric action of the sun's radiation on the earth. According to the last, the atmosphere in sunlight contains a possible electrolytic induction. If this theory is not held in the form given it by its originator, it can be so modified, as the authors have shown,[4] that it does not contradict our investigation regarding the so-called photoelectric dissipation. This phenomenon, discovered a few years ago by Hallwachs, consists in this, that a conductor struck by a ray of ultraviolet light loses negative electricity to the surrounding gas, and it is, as later observations show, in its degree dependent on the nature of the conductor, on the intensity and wave length of the light. Since it can be experimentally shown that the sun's rays act on certain substances of the earth's crust in a so-called photo-electric sense, it is evident that no essential difficulty exists in referring the variability of the potential-fall to that of the insulation. In regard to the yearly period, the theory results about the same as that of Exner; in regard to the daily, it gives, without difficulty, the loss of potential in the course of the day during the summer months; the nightly movement, as well as the irregularities in the winter half of the year, can not be fully explained.

[1] F. Exner. See footnote No. 2, p. 512.

[2] v. Bezold, *Ueber eine nahezu zwanzig-tägige Periode der Gewittererscheinungen.* Sitzb. Akad., Berl., xxxvi, 1888, p. 905.

[3] Svante Arrhenius, *Ueber den Einfluss der Sonnenstrahlen auf die elektrischen Erscheinungen in der Erdatmosphäre.* Meteorolog. Zeitschr., v., 1888, p. 297.

[4] J. Elster u. H. Geitel, *Beobachtung des atmosphärischen Potentialgefälles und der ultravioletten Sonnenstrahlung.* Sitzb. Akad., Wien, ci, 1892, p. 703.

In the process of dissipation of negative electricity in sunlight, as Nodon[1] proves, it is not necessary to be brought to reach the zero, and so in stronger insulation, even the appearance of negative values will, as minima of the daily period, be possible. Perhaps the observations of André[2] are to be understood in this sense. An innate difficulty for this theory lies in this, that the photo-electric dissipation from the parts of the earth covered by vegetation and water has not yet allowed itself to be proven.

The electrical phenomena during the fall of precipitation are characterized in some sort, as already remarked, as disturbances of the normal field. It has been generally stated that the rain is always accompanied by negative values of the potential, but all observers, from Dellmann up to recent times, contradict it. Palmieri[3] has correctly expressed the state of the case, for he says, that when negative electricity is observed, almost always rain falls near by, but the law is not reversible. The inconstancy of the potential-fall during precipitation is characteristic; diminution follows immediately upon the appearance of the lightning. One observes in the diagrams of Kew, Baltimore, Wolfenbüttel, and in the galvanometric measures which Weber[4] carried out on currents in a lightning conductor during a thunderstorm, that changes of sign follow one another so quickly that instruments of great variability and periodicity are necessary to separate them. The existence of both electricities shows that an electro-motive force is bound up with the formation of precipitation. Between thunderstorms and the quietly flowing precipitation, there is found an electric connection, but gradual and with no essential difference. Clouds alone produce similar yet very small changes of potential, so that it often remains doubtful whether they are the principal agents. Only in the mist that lies on the ground in the region of an anticyclone, as Schübler finds, is the potential-fall abormally high, while at the same time the temperature is below the freezing point or near it. From the atmospheric electricity during the fall of precipitation, the peculiar electricity of the latter is to be clearly distinguished. It is, according to the observations of the authors, very variable[5] in its sign, and frequently this is opposite to that of the first. These results agree with the theoretical considerations of Linss, by which the rain clouds are considered as of oppositely electrified layers, parallel to the surface of the ground. As a basis for the distribution of electricity in regions of precipitation, it fails to be entirely satisfactory. Frequently one finds in advance of

[1] Nodon, Compt. Rend., Paris, CIX, 1889, p. 219.

[2] André. See footnote, p. 515.

[3] Palmieri, *Leggi ed origine della elettricità atmosferica*, 1882.

[4] L. Weber, *l. c.*, p. 574. See footnote, p. 513.

[5] J. Elster u. H. Geitel, *Beobachtungen betreffend die electr. Natur der atmosph. Niederschläge.* Sitzb. Akad., Wien, XCIX, 1890, p. 471.

a squall a positive, and in the rear a negative fall. Dellmann and Palmieri have remarked a zonal distribution of electricity.

There are two experiments for the whole phenomena, which can be used for the explanation of precipitation electricity. It was first discovered by Faraday, and has recently been investigated again by Sohncke,[1] in this way, namely, the positive electrification of dry ice crystals through friction on dust-formed water. Sohncke and Luvini[2] have made this result the ground of an extensive theory of thunderstorm electricity. Sohncke deduces in different ways, especially out of the behavior of cirrus and cumulus clouds, that in thunderstorms water and ice coexist. One will readily acknowledge that in the case of hailstones in a cloud the conditions of Faraday's experiments are given. This impression is produced by the frequent high electricity of the slowly-falling snowflakes or of the raindrops which come from a low cumulus cloud. The normal electricity of the air is to be referred also, according to Sohncke, to the influence of a surface of variable height, the isothermal surface of zero degree, over which, through friction, positively electrified ice needles float.

The second related phenomenon has already been mentioned, which was first noted by Maclean and Makita Goto,[3] and recently studied by Lenard,[4] namely, electrification through falling water. When water drops strike on a fixed moist substratum or a larger water surface the surrounding air at the time of impact shows itself as negatively electrified. One must regard it, with Lenard, as very probable that the negative value of the potential-fall, which frequently accompanies rainy weather, is partly conditioned by this process. That this explanation is not entirely sufficient results from this, that negative potential values are also observed in snowfalls.

The origin of the development of electricity, as explained by other investigators, as the condensation of water vapor according to Palmieri, the friction of the air on ice according to Sprung, etc., does not permit itself to be based on experiment. Also, the theory of Edlund, built on the induction through the earth's magnetism, as also the electrical action at a distance of the sun, according to Holtz and Werner Siemens, have not been fruitful thus far for further development.

It is finally possible to consider the problem of precipitation electricity in such a way as to regard the local variations of the precipitation in the electric field of the earth as exclusive sources. Pellat[5]

[1] L. Sohncke, *Der Ursprung der Gewitterelektricität und der gewöhn. Elektr. der Atmosph.* Jena, 1885.

[2] Luvini, *La Lumière electrique*, Paris, XXVIII, 1888.

[3] Magnus Maclean und Makita Goto, Phil. Mag. Lond., XXX, 1890, p. 148.

[4] P. Lenard, *Ueber die Elektricität der Wasserfälle.* Ann. Phys. u. Chem., Leipz., XLVI, 1892, p. 584.

[5] Pellat, *Sur la cause de l'électrisation des nuages orageux.* Jour. de Phys., Paris. IV, 1885, p. 18.

first mentioned the idea that a cloud must receive induction electricity, negative on its upper side and positive on its lower side. If they are torn by the wind, both parts change positions and a discharge between them will be possible.

These conclusions show the fact that the air between the single drops of a cloud is by no means an insulator or separator of electricity in the ordinary sense. The authors[1] have sought to make as a basis of an investigation the electric polarization of the single particles of precipitation in the field of the earth, and the striking together of the large with the small, through which there is a continuous strengthening of a very small initial charge, in consequence of self-induction, just as in an induction machine, which is a probable hypothesis. The remark may be allowed, that for the prosecution of further developments into the field of precipitation electricity there is needed before all a definitive investigation of the amount of electricity which is brought to the earth by rain drops, sleet, and hailstones, as well as of snowflakes.

In regard to electrical charges, our knowledge has been increased through the improvement of photography by Kayser,[2] Trouvelot,[3] Colladon,[4] and others, through which the oscillatory character of many kinds of flashes is shown. Regarding the lengthening of the spark paths by water drops, v. Lepel[5] has published an interesting investigation. The attention of observers at mountain stations may be directed to a communication of Reimann[6] in Schlesien, according to which, during thunderstorms without cirrus, which are at times observed below the summit of the Schneekoppe in the Riesen Gebirge, lightning has been seen to strike out from the cloud into the sky above. Kohlrausch[7] estimates the quantity of electricity coming in a lightning charge by means of the thermal effect of the impact as between something like 52 to 270 coulombs.

Ball lightning, whose existence, after many new confirmative cases, is no more a matter of doubt, is yet a problem as to its mode of existence. Whether in the well-known experiments of Planté an experimental representation ought to be recognized, appears to be

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[1] J. Elster u. H. Geitel, *Bemerkungen über den electrischen Vorgang in den Gewitterwolken.* Ann. Phys. u. Chem., Leipz., xxv, p. 116 u. 121; also, Sitzb. Akad., Wien, xcix, 1890, p. 471.

[2] Kayser, *Ueber Blitzphotographien.* Ann. Phys. u. Chem., Leipz., xxv, 1885, p. 131.

[3] Trouvelot, Compt. Rend., Paris, cviii, 1889, p. 1246.

[4] Colladon, Compt. Rend., Paris, cix, 1889, p. 12.

[5] *v.* Lepal, *Ueber die feuchten Funkenröhren und Gewitterblitze.* Meteorolog. Zeitschr., vi, 1889, p. 216.

[6] Reimann, *Weitere Beobachtungen über Gewittererscheinungen im schlesischer Gebirge.* Meteorolog. Zeitschr., iv, 1887, p. 165.

[7] W. Kohlrausch, *Ein Versuch die Elektricitätsmenge der Gewitterblitze zu schützen.* Elektrotechn. Zeitschrift, ix, 1888, p. 123.

more than doubtful, in consequence of the difference of the conditions of the experiment from those given in nature.

With the building of mountain observatories, the observation of the electric stream known under the name of St. Elmo's fire becomes very much easier. It is especially frequent on the stations at Pikes Peak, Ben Nevis, and the Sonnblick.

Obermayr,[1] in Vienna, has arranged systematic investigations, and has employed different forms of brushes for the determination of the mode of out streaming of the electricity. Recently there has appeared a report on a great number of observations of St. Elmo's fire on the Sonnblick, which, at the instance of the authors,[2] was collected in the course of three years. The sign of the out-streaming electricity depends very probably on the kind of precipitation falling at the same time. An important addition to the geographical distribution of St. Elmo's fire results from a study by Haltermann.[3] It appears that the phenomenon is connected with the same climatic conditions which are favorable to the development of thunderstorms.

Finally, observations which have relation to the electric nature of the polar light may be mentioned. According to Neumayer,[4] at Melbourne, and Nichols,[5] at Ithaca, N. Y., no undoubted electrical action of the polar light could be ascertained, while the same was found by the observers of the Danish expedition at Cape Thordsen,[6] in Spitzbergen. In these places there was, during the exhibition of the polar light, a diminution of the electricity of the air, even to negative values. It is much to be desired that these observations should be repeated, for which the trials by Lemström[7] into the dependence between the electrical radiation and the polar light appear to be insufficient.

It is not improbable that in these places a link in the chain of the phenomena lay concealed, which acted in the path of the electricity from the earth into the atmosphere and back again to the earth. That through such observations also a dependence between the variations of the electric and the magnetic fields of the earth may be brought to light is, according to the theoretical investigations of Schuster,[8] not to be lost sight of, according to which the cause of

[1] v. Obermayr, *Ueber die bei Beschreibung von Elmsfeuern nothwendigen Angaben.* Meteorol. Zeitschr., v, 1888, p. 324.

[2] J. Elster u. H. Geitel, *Elmsfeuerbeobachtungen auf dem Sonnblick.* Sitzb. Akad., Wien, CI, 1892, p. 1485.

[3] Haltermann, *Ueber St. Elmsfeuer auf See.* Meteorol. Zeitschr. VII, 1890, p. 73.

[4] Verbal communication.

[5] *Cf.* Mendenhall, *l. c.*, p. 151. See footnote, p. 514.

[6] *Observations faites au Cap Thordsen.* T., II, 2, *Electricité atmosph.* Stockholm, 1887.

[7] Lemström, *L'Aurore Boreale.* Paris, 1886.

[8] A. Schuster, The diurnal Variations of Terrestrial Magnetism. Phil. Trans. Roy. Soc. of London, LXXX, (A.), 1889, p. 467.

the daily variations of the magnetic elements is to be sought in the electrical currents in the atmosphere.

One will not, in concluding this review of the researches into the field of atmospheric electricity, forbear to observe that the building on sure knowledge is quite small; on the other hand, a full explanation of these problems is anticipated through observation and research. If we consider that in science it is of importance to discover the real questions, then the outlook for the future is brighter. The steady increase in the level of our general knowledge of electricity makes it easier from year to year, in a harmonious working together, to press into the more difficult parts of this field, and to conquer it even more completely for the "physics of the atmosphere," as v. Bezold has briefly called meteorology.

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## 8.—ON THE CONSTRUCTION OF EARTH-MAGNETIC INSTRUMENTS.

Dr. M. Th. Edelmann.

The building of earth-magnetic instruments began with the discovery that magnetic force goes out of the earth, and there has been constructed a considerable number of instruments through the labors of a series of distinguished scholars, and by the help of skillful mechanicians. Especially, Hansteen, Gauss, Weber, Lloyd, and Lamont, and in our time, Neumayer, Kohlrausch, and Mascart, but above all Wild, have done great service in this direction.

Corresponding to the purpose of the instruments, these are next to be divided into station apparatus, or such as is used in magnetic observatories in various positions, and into portable apparatus, when the same is employed in scientific expeditions, or in measuring the temporary differences of magnetic force. The station instruments are again divided into absolute, which serve for the determination of the momentary values of the magnetic constants, and into variation apparatus with which one determines the course of the variations of the earth's magnetism, or allows the same to be automatically registered. The limits of the present paper do not permit the introduction of many figures, which would be properly sought, of magnetic instruments; it must here suffice to mention the prominent constructions, and to refer to the places where drawings and descriptions of them are found. Yet I have given some interesting or new instruments in sketches, and a short descriptive text. For the making of magnetic instruments in general, it is evident that the choice of the materials out of which they are constructed is an important thing, and furthermore quite difficult. There is needed a piece of steel, which, being of sufficient sensibility for magnetism, retains the same with-

out variation for a considerable length of time. In the experiments of Wild, a Wolfram steel is generally used from the factory of Böhler, especially with the gold mark (very hard); this magnet is made constant by the method of Lamont,[1] which consists in plunging the magnet many times in hot and cold water, or according to the magnetization method given by Stronhal and Barus,[2] consisting of many hours' heating to 100°, between two magnetizations in the same direction. A difficult thing is the choice of the nonmagnetic material employed in making the apparatus (brass, copper, bronze, marble, etc.), because these must be entirely free from all magnetic action. One must, therefore, test even the smallest piece of raw material for its magnetic properties, which is best accomplished by Lamont's magnetoscope (Fig. 1). This contains as an essential part a horizontal needle, *n s*, carried by a lever, *a b c*. At the free end of this needle there rests the balance weight, *b*; from *c* there extends vertically upward the rod, *c d*; it carries on the end the mirror, *S*, and a hook, *f;* this whole complex is stiffly bound together, and hangs on a simple cocoon thread, whereby rotation of the whole can take place around a vertical axis. This needle is also distinguished from a common needle in that the middle point of the magnetic element does not lie in the rotation axis, *c f*, but is separated therefrom by the arm, *a c*. Through this arrangement the needle, *n s*, turns, and with it the mirror *S*, to be observed with telescope and scale when a magnetically acting body is brought before one pole of the needle. This renders it possible to measure the objects to be investigated by simply bringing them near the poles, *n s*, which are covered with thin glass tops, *p q;* all the rest is covered up air-tight. For the attainment of greater sensitiveness, the apparatus can be placed near a hanging auxiliary magnet on the suspension tube, and in every important object tested one can, before the trial by the magnetoscope, magnetize the instrumental parts to be investigated with the help of a strong magnet; electrolitic copper is very seldom nonmagnetic, and must be carefully tested before use; I have also up to this time found only electrolitically precipitated silver pure and faultless.

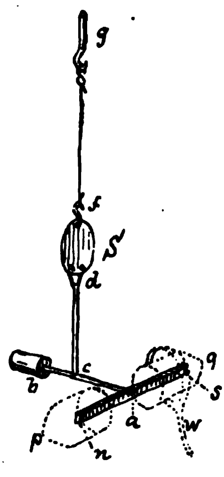

FIG. 1.—Magnetoscope.

## STATION APPARATUS.

### INSTRUMENTS FOR ABSOLUTE MEASURES.

*Declinometer.*—At the outset there was employed for this a magnetic

[1] Lamont, *Handbuch des Erdmagnetismus*, p. 176.
[2] Wiedemann's *Annalen*, Vol. xx, p. 662.

needle turning on pivots terminating in a fine point and swinging over a divided circle. Later it was observed with microscopes (for example, Gambey), as one now sees this used in geodetic and mining instruments[1] and thread suspensions. When Poggendorff learned to supplement the magnetic needle with a mirror in 1826, Gauss constructed in 1833[2] his mirror declinometer. Out of this there was developed the following frequently employed constructions: Weber's portable magnetomer,[3] wherein later Lloyd's collimator readings were employed; Lamont's declinometer,[4] and still others. All these instruments brought into use a geodetic theodolite free from iron, independent of the declinometer, whose telescope was directed on the mirror or collimator of the needle. The collimation error between the magnetic and optical axes of the needle is corrected through reversal of the same on the horizontal axis. These instruments are now not much in use since they are superseded by the so-called magnetic theodolite.

*Inclinatorium.*—The value of the inclination angle can be measured either by means of the needle inclinometer, or by an inductive inclinometer. The needle inclinometer consists of a magnet swinging on its center of gravity about a horizontal axis; the orientation of its plane of oscillation to the magnetic meridian must be determined by means of rotation of the whole about a vertical axis. Both rotations are read on divided circles. On account of corrections of the errors of the center of gravity and collimation, the needle will be unmagnetized and changed in position. These instruments offer a great mechanical difficulty on account of the method of using a frictionless horizontal axis. At present polished round steel axles are used which roll on two horizontal agate planes; in earlier constructions one sees pointed ends, friction rollers, thread suspensions,[5] etc. Older instruments are found constructed by Nairn and Blunt (1733), Dollond (1776 to 1834),[6] Robinson (1830), Ramsden, Gambey. An instrument, the property of the University of Basel, given by Daniel Bernouilli, and constructed by John Dietrich in Basel, obtained in Paris, 1743, the prize of the Academy. In most recent times J. P. Joule, D. Lloyd (Kew model), Mascart[7] and Wild[8] (1890) have devoted themselves to the improvement of these instruments.

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[1] Bauernfeind, *Vermessungskunde*, II Aufl., p. 160, etc.

[2] Gauss and Weber, *Resultate aus den Beobachtungen des magnetischen Vereins*, 1836, p. 6.

[3] *Ib.*, p. 63.

[4] Lamont, *Handbuch des Erdmagnetismus*, p. 224, and *Handbuch des Magnetismus*, p. 152.

[5] Bohn, *Ergebnisse physicalisher Forschung*, p. 655.

[6] Phil. Trans., vol. 46.

[7] *Leçons sur l'électr. et le magn.*, Mascart et Joubert, p. 665.

[8] *Mémoires de l'acad.*, St. Petersb., T. XXXVII, No. 6.

The fundamental idea of the inductive inclinatorium makes use of the following: A coil of wire (earth inductor) is turned in the magnetic field of the earth, the position of the rotation axis fixed through angular measures, which are observed and measured in an induction current passing through a galvanometer, and finally from the strength of the current and the orientation of the axis of rotation, makes a back throw corresponding to the position of the rotation axis, together with the direction of the inclinometer. Weber[1] first learned to turn the earth inductor in a declination plane around a vertical axis, and then about a horizontal axis. The quotient of the two numbers, which measures the corresponding intensities of the induced currents, is the trigonometric tangent of the angle of inclination. In Fig. 2 such an instrument[2] is represented. $R$ is a hard rubber spool of 200 mm. diameter and 100 mm. thickness, wrapped around with 2 mm. copper wire. It can be turned about the axis $X$ by means of the handle $A$ through 180°, forward and back. The horizontal axis $Y$ at the foot of the apparatus, which lies horizontal and at right angles to the axis $X$ (correction for this, $f$ and $g$); moreover, the whole apparatus is constructed of metal entirely free from iron, and provided with all the mirrors, attachments, etc., which control a sufficient orientation of the planes of movement and the rotation axes.

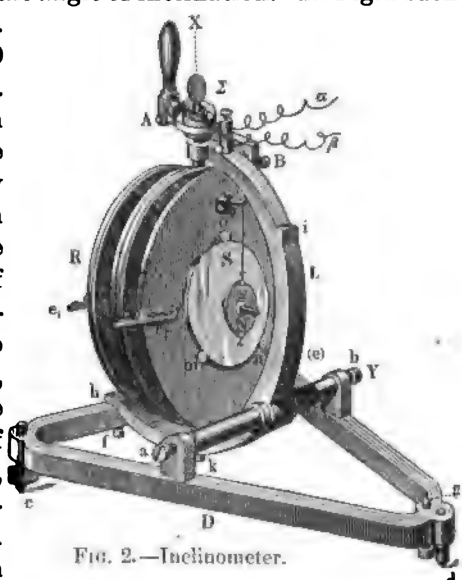

FIG. 2.—Inclinometer.

In the works[3] just cited the means are given of introducing into the calculation the necessary corrections on account of the inconstancy of the galvanometer functions, with the help of suitable branch and supplementary resistances. Schering allows the earth inductor[4] to turn about two axes of direction, which stand in equal angular relations before and behind the position of the inclinometer. Wild[5] gives a picture and description which solve the problem in the most complete form and theory. Two simultaneous rotating induction coils, one with the horizontal the other with the vertical

[1] Poggendorff's *Annalen*, Vol. XC, p. 209.

[2] Edelmann, *Erdmagnetische Apparate der Polarexpeditionen*, Braunschweig, 1883, p. 21.

[3] Also in, *Carl's Repertorium*, 1882, p. 1.

[4] Wiedemann's *Annalen*, Vol. IX, p. 287.

[5] *Mémoires de l'acad.*, St. Petersb., Vol. XI, 467, and Vol. XXXVIII, No. 3.

axis, were first proposed by Bezold, in 1871, for an inclinometer with impulsive measurements, and by L. Weber[1] for the construction of an instrument of absolute measure, and by me, in 1891, for a variation apparatus. Mention can here be made of a construction[2] in which the susceptibility of soft iron to induction is employed for determining the inclination. Very recently, in 1892, Wild[3] has employed a null method, mentioned by Mascart[4] in 1883, for constructing a new inclinometer. In this instrument the spool of 100 mm. diameter, with 1,160 continuous windings, is turned around an axis, whose position is changed slowly until the induced current in the same direction in a commutator completely disappears in a Rosenthal micro-galvanometer;[5] then the axis lies in the same direction as the inclination. By the method of using the later theodolite of Wild this interesting apparatus is contained in a form modified for transportation, as also for use by itself, as it is built as described by Wild in the *Repertorium* of the St. Petersburg Academy.

### APPARATUS FOR THE ABSOLUTE DETERMINATION OF HORIZONTAL INTENSITY.

*Magnetometer.*—The construction of this instrument begins with the famous work, *Intensitas vis magneticae terrestris ad mensuram absolutam revocata, auctore,* Carolo Frederico Gauss, 1833. As mechanicians, Meyerstein and Apel worked on this in Göttingen, and Breithaupt in Cassel.[6] The apparatus described by Gauss was then installed in like manner at the stations of the Magnetic Society: Göttingen, Bonn, Dublin, Freiberg, Greenwich, Kasan, Milan, Munich, Naples, Upsala, Krakau, Leipzig, and Marburg. Since the time of Alexander Humboldt's journey, in 1798, the real development of terrestrial magnetism took place. Gauss used in his apparatus very heavy magnets, of dimensions 700 by 50 by 10 mm. (2 to 6 kilos), with the object of attaining by them mean values. From the Gaussian ideas there have been developed the Weber portable magnetometers,[7] and also two new and smaller instruments; a magnetometer according to Gauss,[8] and a magnetometer with constant angle of deviation,[9] as well as a magnetometer invented by Elliot in London, and, finally, some sensitive apparatus in possession of the Kew Observatory,[10] and the Weber

[1] *Ber. Acad.*, Berlin, Vol. XLIX, Dec., 1885.

[2] Edelmann, *Apparate für naturw. Forschung und Schule*, Stuttgart, p. 84.

[3] *Repertorium für Meteorol.*, Petersb., Vol. XVI, No. 2.

[4] *Compt. rend.*, Paris, Vol. XCVII, p. 1181.

[5] Upperborn, *Electrotechn. Zeitschrift*, Berlin, 1891, Pt. VI.

[6] Gauss and Weber, *Resultate des magnet. Vereins*, 1837, p. 18.

[7] Gauss and Weber, *Resultate des magnet. Vereins*, 1836, p. 63.

[8] Edelmann, *Neuere Apparate*, p. 42.

[9] *Ib.*, p. 8.

[10] *Special Loan Collection of Scientific Apparatus at South Kensington*, 1876.

compensated magnetometer.[1] Lamont introduced, in 1840, as already stated, light needles, which had great relative strength, and, to avoid the disturbing currents of air, inclosed them in little cases, which only allowed free play to the needle.

It was a fruitful idea of Weber[2] to find the horizontal intensity by a purely galvanometric method when a current is carried at the same time through an absolute galvanometer and a coil suspended on two threads, in order to compute from the deviation angles read on both instruments the dimensions of the coils, the moment of inertia of the bifilar coil, etc., the absolute measure of the current employed, and the horizontal intensity. This method was developed and considerably modified by F. Kohlrausch. He allowed the current flowing through a bifilar coil, deflecting itself, to act on a unifilar magnetometer, whereby this is carried to the coil of an absolute galvanometer. Furthermore, he suspended the coil with threads separated from one another, and introduced the well-known bifilar suspension[3] as the means of measurement in the absolute method of determining terrestrial magnetism.[4] Later[5] he replaced the coil, with the current flowing through it, by a magnet, and constructed from it the very interesting bifilar magnetometer. An advantage of this method is that both determinate readings can be made simultaneously. Independently of Kohlrausch the idea came to H. von Wild[6] in 1880, with the help of the bifilar suspension, to work out a new method for determination of the horizontal intensity, and he constructed, in 1883, his bifilar theodolite, which was described and illustrated extensively in the memoir of the St. Petersburg Academy.[7]

*The Magnetic Theodolite.*—For its construction Lamont announced the principle at the same time that he introduced small needles into magnetic measurements and discovered a new collimator reading.[8] The principal difference between the magnetometer and the magnetic theodolite, briefly and chiefly, consists in obtaining from the deviation the determination of the intensity, and is as follows: In all magnetometers the determination of the angle of deflection of the needle is indirect, through the measurement of the two sides of a right-angled triangle, namely, the distance between the mirror of the

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[1] Kohlrausch, *Poggen. Annalen*, Vol. CXLII, p. 551.

[2] Kohlrausch, *Poggendorff's Annalen*, vol. 138, p. 1.

[3] Lamont, *Handbuch des Erdmagnetismus*, p. 117.

[4] *Wiedemann's Annalen*, Vol. XVII, p. 737.

[5] *Ib.*, Vol. XXVII, p. 1.

[6] *Die Deutschen Polarexpeditionen und ihre Ergebnisse*, von Neumayer, 1891, suppl. to Vol. I, p. 46.

[7] Vol. XXXIV, No. II.

[8] Lamont, *Handbuch des Magnetismus*, p. 152; *Ann. für Meteorolog. und Erdmagnetismus, Heft* I, p. 164.

needle to the scale of the reading telescope and the reading on this scale itself, whereby the zero of deviation and the telescope remain in an invariable direction. In the magnetic theodolite, on the other hand, the telescope is movable, together with the deflected image. The telescope remains always directed at right angles to the mirror of the deflected magnet needle, and is read off directly on a divided circle, whereby the telescope can be placed very near the mirror of the needle, while in the magnetometer the scale must be placed at least two meters distant from the needle, in order that the triangulation may afford sufficient accuracy for the determination of the angle. From this there follows for the theodolite important advantages over the magnetometer; for example, compactness, greater constancy in the essential parts of the apparatus, convenience in manipulation, and, especially, greater accuracy in the results, because measured directions for the determination of angles will be more exactly obtained, as in determination of lengths.

Lamont[1] has extensively constructed and used these magnetic theodolites. The more these instruments were employed in the course of time, simpler modifications in their form became known, and many students have been occupied with their elucidation, especially in adapting these instruments mentioned to work under peculiar conditions. Such constructions are well known, as, for example, by Neumayer[2] (deviation magnetometer), a magnetic theodolite by Meyerstein on the occasion of the meeting of the Natural History Association, at Leipzig, in 1872, a theodolite magnetometer by Lloyd (Jones, London), as well as constructions of Lamont's theodolites by Bamberg, Berlin,[3] my own works,[4] and by Mascart.[5] A considerable change in magnetic theodolites from the bifilar theodolites already mentioned was begun by Wild in 1885, and described in 1888 as a "new magnetic unifilar theodolite."[6] I have given a sketch of the same in Fig. 3.

Before the telescope, $F$ (with reading scale and cross threads illuminated by the mirror, $O$), there are two needles, $H$ for the deflection, $G$ for the oscillation and declination observations; by means of pierced wooden boxes with parallel glass windows these needles can be protected from drafts of air. The deflection magnet can be laid in the tubular deflection bars, $R$ and $R'$. The needle, $G$, forms at the same time the counterpoise weight, $F$, whose rotation about the horizontal axis can be read on the circle, $M$. $L$ is the

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[1] In his *Handbuch des Erdmagnetismus*; also, in his series of text books.

[2] *Der Compass an Bord, Koldewey und Neumayer*, Deutsche Seewarte, Hamburg, 1889, p. 40.

[3] *Die Deutschen Polarexpeditionen*, 1882–'83, p. 86 of the suppl. to Vol. I.

[4] *Die Erdmagnetischen Apparate der Polarexpeditionen*, 1883, p. 20.

[5] *Leçons sur l'électr. et magn.*, Mascart et Joubert, p. 661.

[6] *Mémoires de l'academie*, St. Petersb., Vol. XXXVI, No. 1.

principal scale of the theodolite, and stands above the rotating telescope axis. *F*, *H*, and *G* are attached to a circular carrier, which can be rotated about the vertical axis of the theodolite (rotation angle read on the circle *B*). *d* and *e* are clamps by which the motion of the magnets, *G* and *H*, can be regulated.

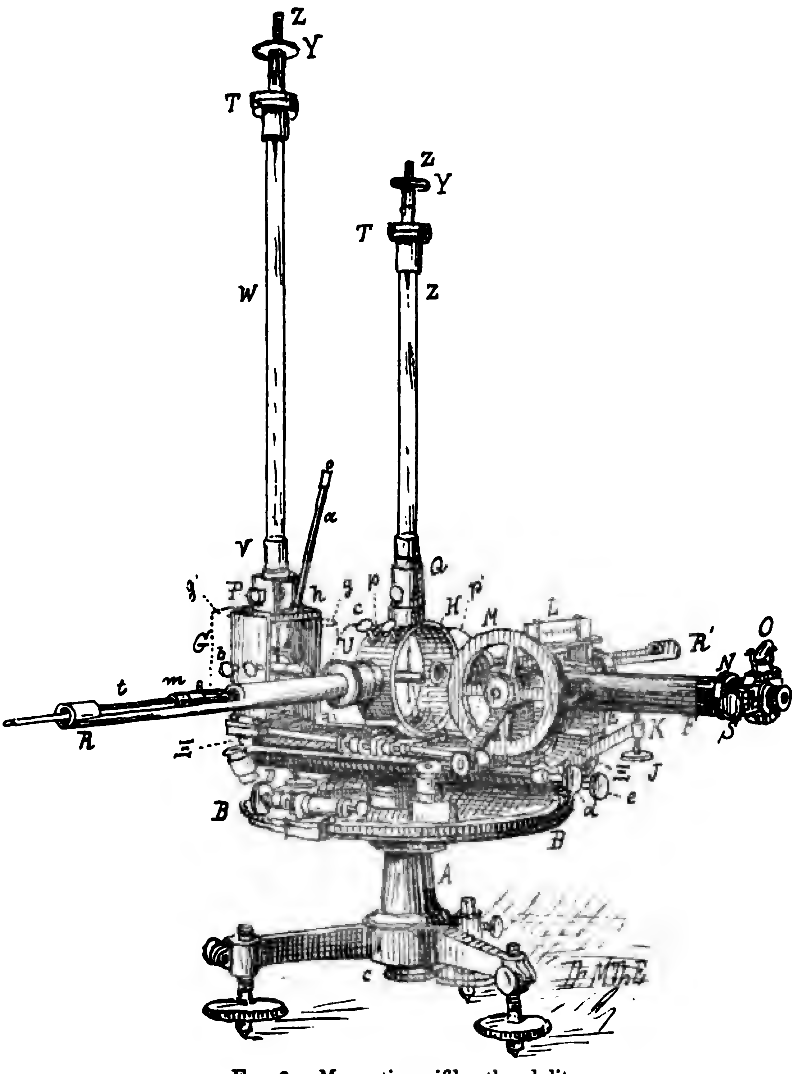

FIG. 8.—Magnetic unifilar theodolite.

*Magnetic variation apparatus.*—The mirror readings were first discovered by Poggendorff, and Gauss himself employed the same in magnetic instruments. In 1837 Gauss had built a variation apparatus for declination, and a similar one for horizontal intensity. The former consisted of a bar magnet suspended from a bundle of cocoon

threads, the latter from two parallel metal wires (bifilar suspension). This variation apparatus was essentially changed by Lamont,[1] who introduced here, also, the small magnetic needles. In place of the Gaussian bifilar, Lamont employed as variometer for the horizontal intensity a combination in which two magnets produced a steady deviation of the magnet needle lying midway between them, and he used for these deflectors at first directors compensated for heat.[2] These consisted in this, that every deflecting long and thin bar magnet exerts an opposite polarity on a clamped short, thick one; the short, thick bar has then less magnetism but a greater temperature coefficient. There arises, therefore, out of the difference of the two an effective magnetism, while the temperature influence is removed. Another method, given by Lamont, uses for compensation of it the deflecting magnets through the so-called strip compensations (two plates of different metals placed opposite each other, as copper and zinc), or through a directed lever, which is put in motion by a zinc bar, in order to approach more closely to the needle, as, through the action of the heat on the deflecting magnet, its magnetism becomes weakened.

In variation instruments for vertical intensity Lamont made use of an idea of Lloyd's,[3] namely, the magnetic induction sensitiveness of soft iron. He placed two iron bars vertically, which were distant about 30 cm. from each other, and between which a little magnet needle is suspended, so that they effect a deviation on it. One of the iron bars is placed with its upper the other with its lower end in the rotation plane of the needle. The stronger the vertical intensity becomes, so much more will each iron bar be polarized, and proportionally will the needle be deflected.

In the last ten years this construction of vertical instruments has been wholly suspended, because they, as Lamont himself had already indicated, do not work with sufficient exactness. In 1882 there was published a new construction, commenced before this time, of Lamont's instruments,[4] in which the iron needles, in U form, with an inclosing rotation body of copper, act as damper, under which circumstances the new phenomena of periodic damping were first observed, as was later done by Du Bois Raymond.[5]

A change in Lamont's horizontal intensimeter was accomplished by F. Kohlrausch,[6] and has been called a local variometer. Lamont[7]

[1] Lamont, *Handbuch des Erdmagnetismus.*

[2] *Annalen für Meteor. und Erdmagnet.*, Vol. I, p. 169; *Abhandl. der* II. *Classe der Münchener Akad.*, Vol. 5; Lamont, *Handbuch des Magnet.*, p. 402.

[3] Lloyd, "Account of the Magnetic Observatory of Dublin," 1842.

[4] Edelmann, *Neuere Apparate*, p. 103; *Apparate für die Polarexped.*, 1881, p. 1.

[5] *Wiedemann's Annalen*, Vol. XIX, p. 130.

[6] Lamont, *Handb. d. Erdmag.*, pp. 210 and 216.

[7] *Ber. Acad.*, Berlin, 1869, p. 807 and 1870, p. 587.

gives an auxiliary method to determine the value of the scale divisions in absolute measure, and he uses for it a deviation process with auxiliary magnets, but his auxiliary magnets are not in construction dependent upon the apparatus itself. Also, self-registering instruments were very early used by this distinguished student. He lengthened the needles, with very light fingers and writing points on them; under the vertical writing points fixed rollers were turned. While the suspension threads automatically lowered and then raised again for a moment the marking apparatus (while the wheels turned by clockwork), each point pressed an indentation in the soot, after which the needles were again free to move. Later, photographic registers were used, and, so far as we know, first by Francis Ronald, 1846 and 1847, at the Kew Observatory, London. Mascart also invented photographic self-registering variation apparatus, in which all three elements record themselves on one and the same sheet of paper, which is stretched on a plane frame carried by means of clockwork, while in the instruments[1] installed at the Kew Observatory three rolls, wound around with photographic sensitive paper, inscribe the traces of the three variometers. In this new variation apparatus the bifilar is used for the horizontal intensity, and for the vertical intensity the Lloyd balance, in which a horizontal bar magnet plays on knife edges.

Schering constructed a variometer for inclination, wherein a magnet needle is carried in a vertical plane of rotation, between two horizontal bifilar suspensions, which are rotated in the plane of the threads 90° from each other.

In 1878 Wild began to turn his attention to earth magnetic variation apparatus, and he gave in 1889 a complete explanation[2] of the same. In Fig. 4 these three instruments are sketched, in which the needles are made of steel bars 11 mm. thick and 110 mm. long. Their periodic oscillations are quieted by thick copper rolls, which at will can be inserted in the tubes of the cover *L*, or can be taken off. For the reception of the tripod in all three instruments, a heavy circular plate of white marble, *N*, is employed. The suspension thread in the declinometer, I, consists of a bundle of cocoon threads; the horizontal intensimeter, II, of two fine metal threads 650 mm. long; *t* is a simple suspension for one, and *T* is a torsion head, reading sufficiently close for the other. For the Lloyd balance, III, there is arranged a total reflecting prism, *K* (according to Wild[3]), in the horizontal position of the scale. In each instrument is placed also a thermometer, *E*, and a direction adjustment, *M*, also a fixed mirror near the one which turns in connection with the variation needle;

[1] Stein, *das Licht in Dienste wissenschaftl. Forschung*, Leipzig, p. 250.
[2] *Mémoires de l'acad.*, St. Petersb., Vol. XXXVII, No. 4.
[3] *Mémoires de l'acad.*, Petersb., 7 ser., Vol. XXIII, No. 8, p. 20.

the first gives control to the unadjusted position of the apparatus, and writes on the register the line of the zero point. The temperature compensation in the horizontal intensimeter is so arranged that the ends of the threads of the bifilar suspension are fixed in two com-

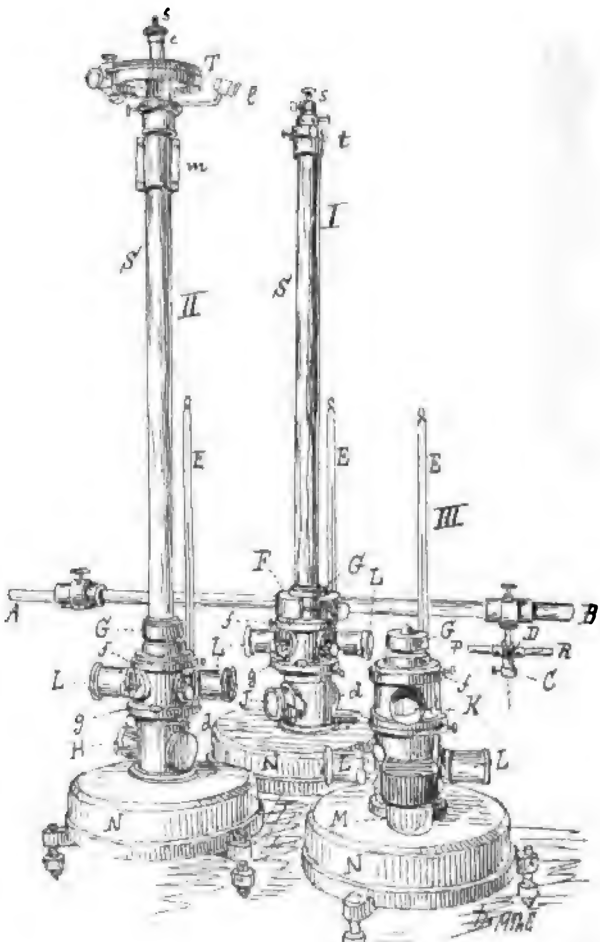


FIG. 4.—I. Declinometer. II. Horizontal intensimeter. III. Lloyd balance.

pensators made of platinium and silver. In the Lloyd balance the same object is attained by bringing the counterpoise of the center of gravity through an aluminum rod in each of the magnet bars. Of great importance is the new device of the Wild variation apparatus for determining the scale values; namely, a deviation bar, *A B*, which has a conical eye, *F*, bored in the middle. By means of this the same bar can be placed on either one of the three variation instruments, to which it fits on cones, *G*, of equal dimensions, and on which can be

arranged the auxiliary magnets *P*, *R*, at equal distances from the variation needles, so as to work as theory demands. Likewise, Wild has invented for these and other mirror instruments a registering photographic scale telescope, which is represented in Fig. 5.

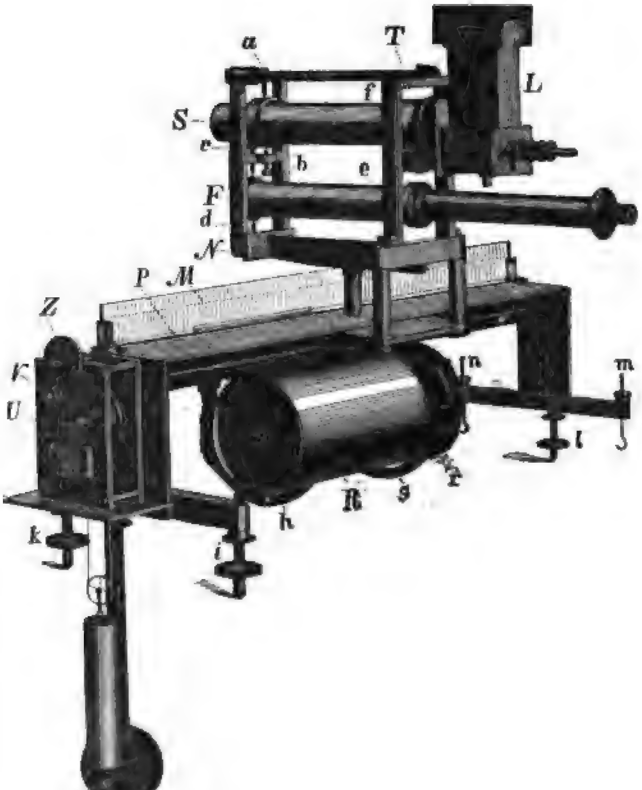

FIG. 5.—Photographic scale telescope.

*F* is a common telescope, *M* is a corresponding scale, *L* an illuminating lamp for gas or benzine, *S* a split telescope, which, on the emulsion paper (stretched on a cylinder inside the drum, *R*), produces a fine point of light by means of the mirror of the instrument and the cylindrical lens. The rollers turn by means of the clock, *U*, and registers for eight days, whereby it is pushed along in the same direction every day. The advantage of this arrangement is that in one and the same position of the variation apparatus, the photographic register, the scale reading, and the determination of the constants can be taken simultaneously, which is naturally of essential influence to the accuracy of the results and the ease of handling the apparatus. Recently, since 1889, it has been sought, in continuation, instead of employing the plane mirror used in variation apparatus up to this

time, to employ a concave mirror of 1,719 mm. radius. Therefore, the objectives *F* and *S* are taken away, and there is put in place of the telescopes a simple ocular, which has been given proper dimensions for this purpose.

## PORTABLE INSTRUMENTS.

Evidently the considerations appropriate for the construction of this apparatus will be different, when it is considered that these instruments are intended for use during journeys. On the one hand, one does not place here that high importance to the extended number of places in the results as in station apparatus; on the other hand, there must be included the greatest possible simplicity, the strongest adaptation to the object in view, smaller weight and volume, compactness, taking to pieces for packing, the greatest possible security against breaking and bending the parts, convenience, and, especially, universal adaptability for astronomical and geodetic determinations; and these conditions will control the construction. For a long time such apparatus has existed, and they are principally the portable declination instruments, which, as ships' compasses, have played the greatest role of all magnetic instruments, extending to a great series of very interesting constructions. Regarding this, one finds extensive examples in the publications of Koldeway and Neumayer, issued by the *Deutsche Seewarte, Der Kompass an Bord*, Hamburg, 1889. Since the middle of the seventeenth century there has been known, also, the portable inclinatorium;

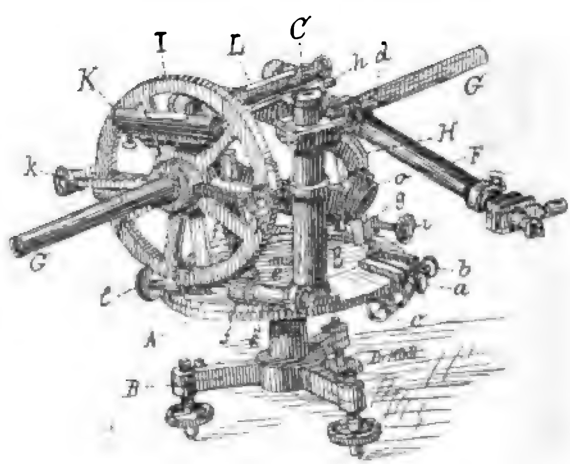


Fig. 6.—Wild portable theodolite.

for example, in 1773, such as that by Nairn and Blunt, for Captain Phipps, in a north pole expedition. Finally, since the journeys of Alexander von Humboldt, there arose the necessity for portable instruments for the determination of horizontal intensity, in consequence

of which Hansteen's[1] oscillation apparatus was invented. Finally, epoch making in regard to such instruments was Lamont's celebrated portable theodolite (1847), which has been described in a great number of text-books, but especially by Lamont himself, in the *Berichte* of the Munich Academy. It has been the basis for all such later apparatus, although the form has been many times changed; for example, by H. Lloyd, Elliott, Neumayer, Meyerstein, Perry, Mascart, and others. In 1892[2] H. von Wild completed new magnetic portable instruments, and, 1893, an improved form, not yet published, which is here explained, with drawings and description, as an example of such instruments. (Sensitiveness of the results: Declination and inclination, $\pm 20''$; horizontal intensity, $\pm 0.0002$ of the total force.)

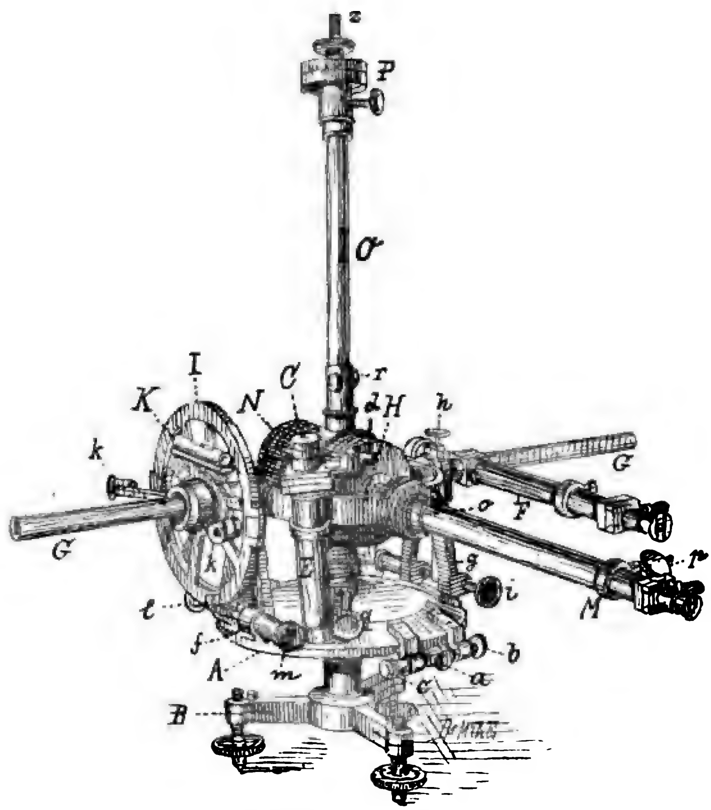


FIG. 7.—Combination for declination.

1. *The Wild portable theodolite* (model 1893).—Combination as a geodetic or astronomical universal-theodolite, Fig. 6 (determination of the astronomical meridian). Thick horizontal circle, $A$, of 170 mm.

[1] Lamont, *Handbuch des Erdmagnetismus*, p. 253.
[2] *Repertorium für Meteor.*, St. Petersb., Vol. XVI, No. 2.

diameter, divided into 10′, on tripod *B*, axis detached; fixed set screw, *a*, micrometer, *b*, thread, *c*, for horizontal rotation. Reading with two microscopes, *C*, attached to the alidade; 30 divisions of the limb become 29 divisions of the micrometer, under which the movable ocular turns with a rapid screw, *d*. Illumination of the limb through long openings in the sides of the microscope tube, *E*. Conical hole, *e*, in the middle of the alidade, for placing the three needles of declination, oscillation, and deflection. The horizontal axis of rotation lies on the two supports, *f*, *g* (slow motion, *h*, micrometric, *i*), and finally with the two deflection bars, *G*, *G*, can be turned and divided in the middle by the ring, *H*. To the right of this is the telescope, *F* (provided with three vertical and one horizontal thread in the ocular sunglass and ocular prism for zenith observations; as also cross-wire illuminations from the axis); on the left, a thick, divided circle,

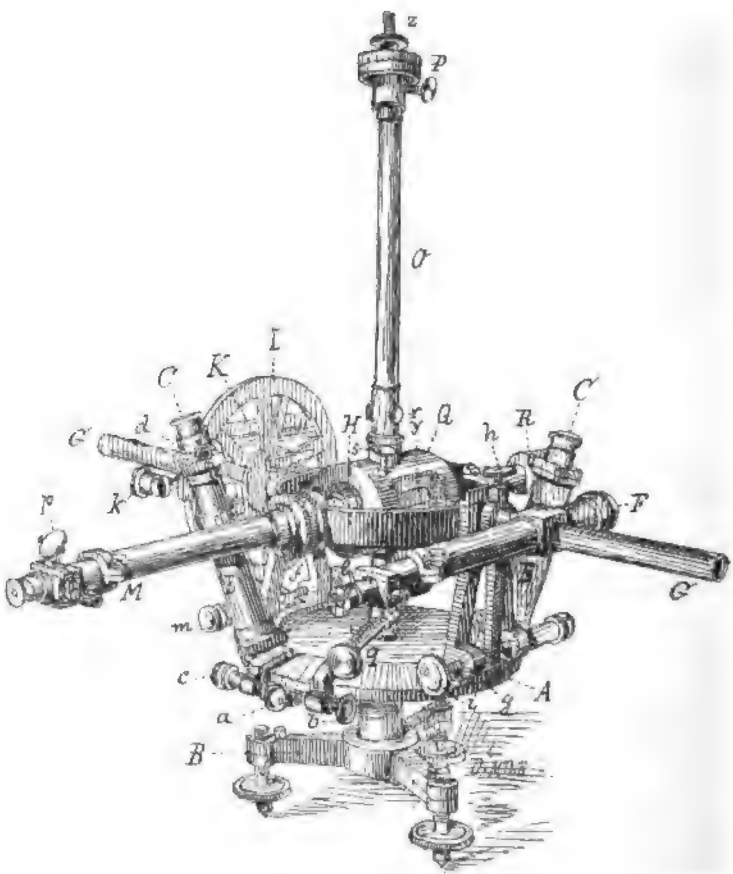


Fig. 8.—Combination for oscillation observations.

*I*, 140 mm. diameter, with verniers under the reading glass, *k*, reading to 20″; the alidade set by the level, *K*, screw, *l*, thread, *m*. In

reversing, the horizontal axis exchanges its rolls, *l*, *m* and *h*, *i*. The level set on the horizontal axis, *L*, has a scale of 10″.

2. *Combination for determination of declination* (Fig. 7).—In the eye, *o*, of the ring, *H*, is a telescope, *M*, with ocular micrometer and illuminated cross threads (from behind by means of a small prism and mirror, *p*). This telescope is set by the reflected image of its cross threads on the reversible declination magnet (steel cylinder of 60 mm. long, 10 mm. thick, with attached mirrors); this magnet is attached to the needle, *N* (the most part wood), and brought to rest through the attachment, *g*. Suspension tube, *O*, with torsion circle, *P*, the length of thread corrector, *z*, thread securer, *r*. For the adjustment of the threads, there is a brass cylinder, with polished mirror, set in place of the magnet needle.

3. *Combination for oscillation observations* (Fig. 8).—In determination of the horizontal intensity: as in the preceding section 2, but with another needle, *Q*; inside the same (on account of the determination of the moment of inertia) a mathematically exact cylinder

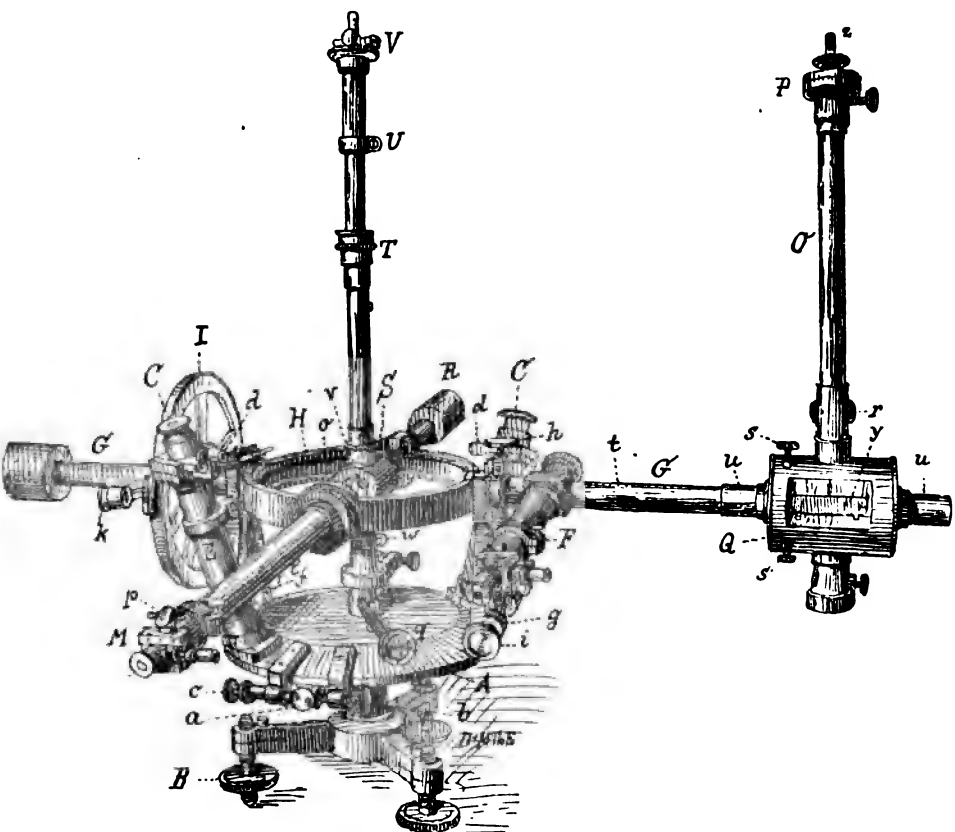


Fig. 9.—Combination for horizontal intensity.

with polished mirrors on the ends, 60 mm. long, 10 mm. thick, or 50 mm. long and 10 mm. thick. The oscillations are observed on the micrometer scale of the telescope, *M*. By two screws, *s* (see Fig. 8), the oscillations magnet *y* can be fixed exactly in the middle of the magnet *Q*. *R* is the counterpoise of the telescope *M*.

4. *Adaptation for deflection.*—Observations for the determination of the horizontal intensity, Fig. 9. The oscillation, now deflection, magnet, *y*, is, together with its case, *Q*, be placed at two different distances on the deflection extension bars, *G*, *G*, the distances of the same by means of verniers, *u*, being read on the scale, *t*, of the bars; through this arrangement Wild avoids the influence of temperature on the magnetism of *y*. The deflection is read by means of the telescope, *M*, on a magnet needle, *v*, in the strong damping case, *S*. A quieting apparatus, *g*, needle arrester, *w*, thread corrector, *T* and *U*, distortion apparatus of the threads, *V*. Corresponding to the two principal magnets are the two needles (steel cylinders with polished mirrors); length, 28 mm., thickness, 10 mm., or 40.2 mm. long and 8.2 mm. thick.

5. *Arrangement for the determination of the inclination* (Fig. 10).—For this there is employed a coil, *W*, surrounded with many turns of thin copper wire, which is turned over by means of the crank *x*, and gives

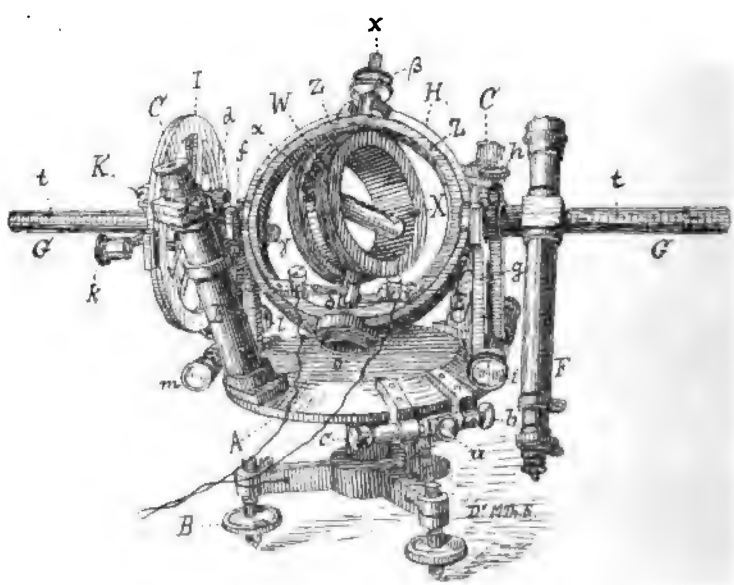


Fig. 10.—Combination for inclination.

no current when the rotation axis is exactly parallel to the direction of inclination. This angle is read on the circle *I*. One obtains this setting easily, as follows: When a current in the same direction in the commutator, *δ*, is carried through an accompanying Rosenthal

micro-galvanometer, constructed as a portable instrument (sensitiveness 0.1[8] Amp.), the complete loss of the current is brought about through gradual position changes of the horizontal and vertical axes of the theodolite (and thereby of the rotation axis of the coil, *W*). The vertical position of the axis of the rotation inductor *W* is accomplished through the level *X* (correction apparatus $\alpha$). *W* is held by means of the correction screws, $\beta$, in the ring, *Z*, which fits into the ring *H*, and is held fast by the screws $\gamma$.

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## 9.—ON SOME IMPROVEMENTS IN MAGNETIC INSTRUMENTS.

Dr. M. Eschenhagen.

It is a remarkable fact that the instruments serving for magnetic observations do not always give the same results, even when they are on the same principle and are constructed for the observation of the same magnetic elements. Thus, for example, two magnetic theodolites, each of which gives the declination accurately to one-tenth of a minute of arc, may yet differ from each other more than a full minute. For the determination of the horizontal intensity the results are unsatisfactory, as the investigations of Rijkevorsell and Solander show. It appears, furthermore, not less probable that the instruments serving for the observation of variations also show similar discrepancies, although the comparison has here been seldom carried out. The origin of such deviations can, on the one hand, be ascribed to errors in the theoretical assumptions lying at the basis of the construction of the instruments, and, on the other hand, they may depend upon actual errors in their construction. Among the first are, for example, the assumptions regarding the computing of the distribution of magnetism in the magnet bar. Of the latter, on the other hand, are certain great errors of observation, and possible peculiar construction of the instruments, so that every observation is always made with a like sign, these not being properly classed as an error of observation. For comparable magnetic researches it must be of great importance to determine at least the largest of the so-called errors which we can designate as constant; but, furthermore, it must be our effort to investigate the origin of these and at the same time make it possible to obviate them.

At the time when the terrestrial magnetic investigations were essentially in the hands of astronomers it was perhaps too soon to employ the same sharp astronomical observations in a science as yet lacking the physical foundations. Until recently the magnetic observations remained for the most part in the hands of physicists and meteorologists, yet the more exact knowledge in conducting experiments with the accurate astronomical methods must not be omitted.

It is the object of the present paper to call attention to certain points in which, through the improvement of the instrumental means, a greater precision in the methods of observation and in the results can be reached, and in this way perhaps allow a contribution toward the diminution of the constant sources of error which have been mentioned.

In an earlier publication of the author, in the appendix of the part of the German polar work referred to,[1] different experiments have been referred to which were made at the German polar stations on the magnetic instruments; certain suggestions for improvement are made; furthermore, in a later work,[2] some remarks were made upon the progress in variation instruments of the Potsdam Observatory. On account of brevity some of these remarks can here find a place only in abstract, and it is necessary also to refer to the papers which have been mentioned for a complete explanation. Most magnetic measurements rest upon angular measures. When we next consider for a moment the absolute observations we find that the angles are measured either by means of the theodolite, and generally by means of a divided circle, or again by observations with a scale and mirror; the last kind comes in use only for certain methods of intensity measurements, but is more largely used for the observations of variations.

In the determination of the absolute declination it is accomplished by means of the angle between a fixed direction (the astronomical meridian or the direction to a mark) and a variable direction generally represented by the axis of a suspended magnet. Both must, therefore, be determined with equal accuracy.

Since one in a fixed observatory needs to secure the determination of the astronomical meridian only once through a great number of observations of a high degree of accuracy, if its deviation from one or several sight lines on fixed points is known, it is sufficient afterwards, in determination of the declination, to set upon these points at the beginning and conclusion of the observations, and also between several series of observations.

In order to make this setting quite convenient there are, for example, in the theodolite of the Potsdam Observatory four vertical threads fixed in the field of view of the ocular, which one after another are brought into superposition with both marks, (1) a distant church tower, (2) a screen with a small hole lighted from behind; also an artificial star, and then they are set on the mark (1) beginning on the threads 1 to 4, one after another; at the end, on the other hand, in the order 4 to 1; and in the same way mark (2) is set in three series of

[1] *Internationale Polarforschung*, 1882–'83. *Die Deutschen Expeditionen.* Vol. I, App. 1, p. 21.

[2] *Einige Bemerkungen zur Aufzeichnung der Variationen des Erdmagnetismus. Meteorol. Zeitschrift*, 1892, Vol. IX, p. 450.

observations forward and backward. Since the circle divisions give one-twelfth of a degree, the drum of the microscope head allows it to be subdivided to 0.01′, so that one can obtain the direction of the astronomical meridian relatively to the known azimuth of the marks to an accuracy of 0.03′. It is essential that all the marks lie as nearly as possible in the horizon, so that they can be set upon with a magnet's telescope lying nearly horizontal. The movement of this telescope in the old instruments allows very much to be desired, especially when this lies eccentrically. It is very necessary to devote much care to this point, and to regulate the movement and the setting according to the rules of the well-balanced telescope of the altazimuth instrument, while the raising and lowering, as well as the supporting by a screw under the tube of the telescope, is by all means to be rejected.

One will best satisfy himself of the usefulness when he observes if, in raising or lowering the telescope, a fixed object stays behind the thread, or whether, in a considerable movement at the middle of the cross threads, a point chosen at a distance moves up and down on one of them. If this is not the case, there can be obtained different values of the meridian by settings at different heights, and then one must take care, through better leveling of the instrument, or correction of the position of the axis, to make the errors disappear, since it will not be eliminated through the common methods of observation. The great difficulty in determinations of declination consists in fixing the magnetic meridian. Aside from the fact that the position of the magnetic axis of a needle is generally only mathematically defined, there is this in addition that one has to do with a movable object, which is brought only with difficulty into a quiet position, and that, furthermore, this moves with the time. The deviation of the position of the magnetic axis from a fixed collimator line ought to be eliminated by a reversal of the bar, but it must be questioned whether this surely happens, because an uncertainty in the determination of this error will probably be the cause of the nonagreement of different magnets. If we consider for a moment here rough settings on a point, there arises, concerning the accuracy of the methods, principally the two following points: (1) The magnet carries fixed to it a plane mirror, and brings the axis of the telescope and the normal of the mirror into superposition, while the image of the cross threads is brought so as to be seen in superposition with the direct. (2) The common tubular magnet consists of a lens covering one of the ends toward the telescope, of which the focus is found at the other end of the magnet, illuminating a glass scale, which is seen in the telescope as a setting at an infinite distance.

By both methods the collimation error of the magnetic axis and

the optical axis of the mirror or collimator will be eliminated through reversal of the magnet (stroked from above and below), but it only seldom is possible to make sure that the images before and after the reversal are actually at the same height, which in the interest of the reduction of the influence of the above-mentioned sources of error is desirable; yet the circumstance that the auxiliary part of the mirror, namely, the lens and scale, can be fixed on the magnet in an entirely invariable position makes also the position of the images again uncertain. In order to here reach the best possible condition the mirror on the tubular magnets serving for the observation will be polished on the circular end surfaces, which to the mechanic was first possible after overcoming some difficulties. Although it can not at the same time be accomplished that the normal to the mirror coincides with the axis of the magnet, yet the constancy of this collimation error is certainly secured, and the images remain the same in height and in sharpness. In order to illuminate the suspension of the magnet before and behind, and especially the threads on which it is hung, to secure an invariable tension, and with it a constant torsion, the double hooks in which the magnet is slung can be clamped by fixing the upper circular part of the suspension between two hooks which can be moved toward each other by screws. Hereby every injury, especially the elastic variability of the torsion, can be avoided, and the installation of a magnet secures, as the explanation has shown, a not unessential increased precision. But previously it was necessary to dampen the movements of the magnet, for which one will best select a fluid damper, in which will be hung on the lower part of the steel of the magnet a damper in the form of a cross bar, which dips in a vessel with vaseline, the wings of the damper containing some holes, whereby the setting gains in accuracy. It is necessary that the wings of the damper should be placed far enough under the upper surface of the fluid, that the surface tension can not exercise any influence on the setting. The damper wings can also be raised from outside by a lever, whereby a quick control of the accurate setting is possible. A thick fluid, like glycerine, hastens the damping, but it ought to be employed only with very heavy magnets. Besides this a stopping bar can be used to advantage, but it is not a necessary condition.

Now, also, the method of setting the threads themselves can be refined. While one frequently makes the setting in such a way that the mirror image of the cross threads makes equal deflections on both sides of the middle thread, it succeeds fully in the case of quiet magnets to make use of setting by bisection. For this purpose one has in the middle of the field two nearly double threads, and right and left, at greater distances, a somewhat stronger single thread. The mirror image contains naturally the same threads, yet one does not

bring the whole system in superposition, but makes two settings in such a way that, one after another, each of the outer reflected threads is brought between the two directly seen double threads. This bisection permits a very close setting to be made, and recommends itself as superior to the superposition of the images. The circumstance that one takes two settings, which must differ from each other by a constant quantity, is a very good control, not only during the observation, but also on the computation, since it is seen that the repetition gives undoubtedly more accurate values than the single observation. So must the difference between each two settings in the Potsdam instrument amount to 13.5′, and every greater deviation from this value must be an error, or may probably indicate the occurrence of a magnetic disturbance. In order to eliminate the last one must undertake in a fixed observatory careful control observations. It is not sufficient to take the variations of the photographically recorded curves if one will determine the declination accurately to 0.1′, but there must at each single setting follow a nearly simultaneous reading of the corresponding variation instruments.

For signaling the corresponding time breaks in Potsdam, an electric light signal has worked very well. The observer at the variation instrument has placed before him a little glow lamp, which, on a pressure of the observer at the theodolite, brightens up. This takes place when the latter has made an approximate setting. If the setting is exact the contact will be broken, and on the lamp going out the other observer reads the variation instrument after he has placed his eye at the telescope, during the burning of the lamp, and has steadied himself before the pier of the instrument. The bringing of an electric current near a variation instrument is without influence, when make and break charges always lie together, or are developed one after another, and the little glow lamp (of 10 volts) is not less than one meter distant from the instrument.

The reading of the variation instrument must, in the case of the declination, naturally be at least to 0.1′, when this degree of accuracy, as is the case, for example, with the Potsdam instrument, is to be reached in the final result. As heretofore, a repetition of the observation and grouping after a definite systematic scheme is essential, as has been already shown, and need not be explained again here. Since in determination of the torsion of the thread the use of a torsion magnet is necessary, it is very important to give the same equal weight and form, and as nearly as possible equal moment of inertia. One can, in this case, derive the determination of the torsion factor, which depends essentially on the ratio of the magnetic moments, very simply from the oscillation periods of both magnets, which one needs to determine only approximately from a shorter series of transit observations. This method is shorter and more agreeable than the

torsion through the rotation of a torsion circle, and ought, when the torsion correction is small ($<1'$), to be sufficiently exact, and to lead less into error than the other method, since one does not need to change the threads on their supports, and therefore keeps clear of the uncontrollable influences from the same. It has already been mentioned that the tension of the threads during the observation is always the same, and also how they are properly arranged for this purpose. Furthermore, it should be remarked that threads of copper wire of 0.04 mm., with a load of 75 grammes, are very well chosen. In the use of such threads one should take care that they are well clamped at the ends, and that fastening to hooks is to be avoided.

In both determinations of the absolute horizontal intensity the angular measures play a very important rôle. Since in deflections, according to the first Gaussian theorem (deflection magnet at right angles to the meridian, and lying in the first magnetic vertical) on theoretical grounds only small deflection angles of 4° or 5° ought to be employed, so that the influence of a small error (about 0.1′) is of more weight than in larger angles of from 25° to 45°. Since the changes of declination always enter with full effect, it is clear that the observation method of Lamont, in which the deflection magnet stands at right angles to the needle, and therefore the formation of greater angles takes place, must be sufficient; when otherwise, the angles can be measured with equal accuracy. The magnet will be placed in these cases at definite distances on a bar, which turns with the alidade, and will, therefore, always remain at right angles with the needle. There are kept at Potsdam, over the parts of the bars on which the magnets lie, a pasteboard cover with tin guides to slide on. Through a small lid the magnet can be laid in and taken out again; it remains under the cover pretty well protected from the changes of temperature, whose influence, it is well known, is very considerable, so that the true temperature of the magnet, by means of a thermometer pushed into the hollow, can be determined with accuracy to 0.1°.

If a tubular magnet of the kind described with a polished mirror is to be used as a deflection and oscillation magnet, one will employ in the place of the two oscillations the well-known method of observation by telescope and scale, and will have fewer changes of the moment of inertia to fear than with an attached mirror. A simplification will furthermore be secured in the determination of the moment of inertia, because the placing of the weight, by shoving the heavy copper cylinder of about double length into the tubular magnet will be possible. Such a fastening, which allows itself to be placed approximately by marks, ought, for the sake of good orientation theoretically, to be the best, since it practically is inferior to no other, when it is possible to construct it of homogeneous material. In respect to the

oscillations a point should be chosen which is as free as possible from influence on the results. One should see to it that in the oscillating magnet both magnetisms are entirely symmetrical to the rotation axis; on the other hand the magnet should hang quite horizontally. Since we do not know about the exact symmetrical arrangement of the magnetism the magnet is brought to hang exactly in the geometrical middle. The bar should also be horizontal when there is no magnetism at hand. If the bar is magnetic, one end bends down unless the other has a little additional weight. But by this the material symmetry is disturbed, and one does better to put on the magnet a suspension hook, about three centimeters long, which, with a cross steel parallel to the magnetic axis, catches on a dou ble hook. By this means will the action of the earth's attraction be reduced to a vanishing quantity, and one has obtained material and magnetic symmetry about the rotation axis to the best possible degree.

Especially is it important to provide the magnet with two suspension hooks, so that one can bring it to two suspensions differing about 180°. The agreement of the periods of oscillation in two positions gives a security for the complete fulfillment of symmetry of the rotation axis. One has by this construction at the same time made more easy the transportation of the magnet as well as the use, and also in deflections, making the exchange from above and below, thereby exerting a certain control over the usefulness of the magnet in respect to the homogeneous distribution of the magnetism. The cylindrical form, perhaps especially that of the hollow cylinder, seems to offer the best guarantee for a symmetrical distribution of magnetism about the horizontal axis, and ought, therefore, to be the most favorable for magnetic measures, because they possess a high specific magnetism. An improvement ought perhaps to be expected in the manufacture of magnet tubes, by the employment of the process of Mannesmann in making steel rods, in which the material rotates in the boring, and therefore is distributed homogeneously. Regarding the proper degree of hardness, investigations have already been carried out,[1] yet it appears that no generally valuable results are to be obtained thereby.

The cylindrical form ought also to be the most suitable for the inclination needle, on account of its high specific magnetism, in which the fineness of the method of the angular measures, unfortunately on account of the small sensitiveness of the position of the needle, have up to this time found no way of application. The commonly used needle, in the form of the rhombus, has for them, on account of the pointed ends, the advantage that the magnetic mass is near the ends and, therefore, the poles would be very little distant from them. This form is, however, most unfavorable, and there is

[1] Strouhal & Barus; also Holborn, *Ueber das Härten von Stahlmagneten. Zeitschrift für Instrumentenkunde*, 1891, p. 118.

lacking, therefore, up to the present time, in all observations with the needle inclinatorium, the accuracy of the measures of the angles which prevail in the declination. To enter upon the indirect methods for the determination of the declination would here lead too far, but there are several important methods which have many advantages, and, after sufficient trial, would be found without doubt to be very useful. We leave now the absolute measures and turn to our instruments which serve for the observation of the variations.

A fundamental condition for the construction of the variation instrument appears to have found general acceptance, and that, too, rightly in the experience of the polar expeditions; for the derivation of the variation, the reading of only one instrument should be necessary, while the data of a second is of account only for certain computations of correction terms of a higher order, as, for instance, the reading of the declination, which allows in great oscillations a reduction to a correction factor for the bifilar. Since the induction in soft iron, on account of the difficult theoretical treatment, will only seldom be available for the reduction of the variations of the vertical intensity, we are restricted to the three instruments, unifilar, bifilar, and balance, which, in good constructions, ought to supply all demands sufficiently, especially when the room in which these are installed can be kept dry and at a uniform temperature. An important question is the determination of the degree of sensitiveness, to which we will next turn.

In Munich, in the year 1891, it was agreed by a great congress of directors of the meteorological magnetic observatories that the sensitiveness for self-registering instruments should be established as follows: Declination, 1 mm. = 1′ (minute of arc); horizontal intensity, 1 mm. = 0.00005 C. G. S.; vertical intensity, 1 mm. = 0.00005 C. G. S., while for the time scale of the registered curves the length of 15 mm. per hour was regarded as sufficient. This agreement of the scale in the notation of the different observatories is naturally of important consideration for the exchange of curves, since the same facilitates the desirable synoptic studies of individual remarkable phenomena. There is no question that the prescribed scale can be adopted by all observatories, but on the other hand it can not be executed in harmony, because through the heightening of the sensitiveness of the scale in ordinates and abscissas, truly an important thing to be accomplished, an increase in the value of the record can be sought. The attempt has been made to obtain such a movement in the magnetic observatory at Potsdam, and indeed, as we must say, not without result. The variation from conformity can be made inoffensive because the curves to be given in exchange can be reduced to the desired scale. At this time a regular exchange has been carried out only by a very few observatories, and also this is restricted to a choice of

interesting disturbed curves. It also enters into the question that a regular exchange of all the curves would be a very inconvenient and expensive task, if the copies consist of the single length 15 mm. per hour, with also the corresponding extension of 36 cm. per day. It would be easier if the length were only half as much as was agreed upon, since, for example, by means of a common photographic camera, a reduction of the three curves of one day could be produced, and the necessary number of copies could be easily taken directly from the plate 13 by 18 cm., or 18 by 24 cm., or could be prepared by a single impression. Thus, it could be accomplished that without important expense reduced copies of interesting days could be regularly sent, for example, monthly; also the size is such that at the end of the year the complete reproduction could be made into a publication. I believe that such a method of exchange would commend itself to a greater number of observatories, and would bring out more results than the sporadic sending of copies in the original, as at present prevails. On the reduced copies it is possible also to afford a good view of remarkable phenomena, and there remains the privilege, in case further information is desired, to send for the original curve. I think also that next the possibility of the comparison of the forces must be afforded, since then also the points of comparison will not be lacking. It often happens, in all copies to be given in exchange, that the time scale is equal, so that in superposing them somewhat equally simultaneous coincidences in the phenomena appear. The magnitude of the indentations comes in the second line as the accurate comparison, yet affords a utilization of the never comparable scale values, to the reduction to absolute value, so that somewhat larger deviations are not the main question, whereas the reduction of the ordinates through photography has not a scale entirely in agreement.

In Potsdam the time scale has been given, through a larger cylinder of the register, an extension of 20.5 mm. per hour. Hereby, and in connection[1] with a very good concentration of the rays, brought together to the focus, which renders it possible that the curves possess a thickness of only 0.25 mm. to 0.40 mm., so that it is possible to recognize a series of phenomena, as, for example, a series of small oscillations of the needles in thunderstorms, as well as in earthquakes, which in the curves of the Kew magnetograph very frequently get lost.

The improvement in the sensitiveness of the apparatus at Potsdam was next attempted in the magnet balance. It was sought to give this instrument, which possesses a Mascart-Carpentier construction, a sensitiveness so that 1 mm. corresponds to 0.00001, that is about fivefold greater than the above. Later, this was reduced to one-half through changes in the instrument. Since the balance evidently

[1] See the work referred to, *Meteorolog. Zeitschrift*, December, 1892.

possesses a very good knife-edge, the number of oscillations was very much multiplied, and the curves showed many more details in the small waves. It is not improbable that in fact the small deflections of the vertical intensity will be of especial importance, through comparison with the phenomena of atmospheric electricity. The reason why the high sensitiveness did not allow itself to be obtained for a longer time was the circumstance that the observatory in the first years of its establishment had still strong changes of temperature, so that the instruments were not sufficiently compensated, and in extreme temperatures became unequally balanced. Yet the strongest disturbances have brought no upsetting to it, only the bright point often fell outside the arc, 19 cm. wide. This danger is, indeed, in very high sensitiveness, the one most to be feared, since there is an overstepping of the arc in special cases; for instance, in disturbances like the 13th of February, 1892, also in the established normal sensitiveness resulting. Yet it is possible to restrict, considerably, the number of such cases, since probably they can be made of higher sensitiveness by the employment of the threefold mirror which has been described in the paper already cited. The three corresponding illuminated points possess a triple amplitude, as at Potsdam an angle of 90°. Greater disturbances ought to happen only in the polar regions, in which certainly one will work with only half the sensitiveness. The use of the threefold mirror gives, frequently, a simple means to sufficiently measure the angular value of the excursion, such as is possible through exact measurement. It is easy to measure the angle of the three normals of the mirrors with a good theodolite to 0.1′, the distance of the corresponding illuminated points, which are reduced to two on the cylinders by the approach of a deflection magnet, and gives without anything further the arc belonging to the angle as ordinate in millimeters, including the correction for shrinking the paper, but not the correction for torsion.

One could, for such days as those for which the arc was not overpassed by the middle point, namely, for the points proceeding from the lateral mirror surfaces, which do not come upon the corresponding cylinders, use the same on collateral cylinders, which are allowed to remain for a whole month in order to secure useful marks for the photograph arcs. Thus, one obtains a picture of the mean monthly deflections, when one of the points shows the month throughout every day on the equal arc; one can also, furthermore, obtain the daily and monthly extreme values when a point falls throughout a month on an invariable arc kept in the same place. In greater disturbances, naturally, the picture will be incorrect, but the cost of the trial is small since only one arc is necessary for one month. On the contrary the construction of the magnetograph will be complicated, and the extension of this idea restricted thereby. The employ-

ment of a triple mirror is, on the other hand, simply and easily brought about, when it is introduced in the first setting up of the instruments.

The question finally arises whether it is not better to set up two systems of variation instruments, one of which is not sensitive, and the other highly sensitive and comes into actual use in registering great disturbances, and, furthermore, avoids the difficulty of that cooperation of self-registration, while it is easy and important to give to the one system serving for direct reading a high sensitiveness, as it will also be necessary to do for the accuracy of the absolute measures.

The direct eye readings ought in many cases not to be discarded, especially when there are very quick changes in the earth's magnetism, or when there takes place at the same time certain attendant phenomena, whose causes are to be investigated together, as, for example, in cases of the polar light. But, on the other hand, a number of very frequent eye observations can only be secured by great labor, when it is necessary, but not so complete a picture will be given as the registering curves furnish; yet it is indeed possible to connect the direct single observation with the immediate impression of another second occurrence to give a suggestion for establishing the cause.

It is not impossible that this method of simultaneous observation may open up an important extension through an indirect process of observing the magnetic variations, which has already been given in the report of the German polar work.[1]

This method is based upon a proposition first made by Werner v. Siemens in the German polar expedition of the years 1882–'83, and which was carried out by the leader of the expedition in Cumberland Sound, at Kingua Fjord. An isolated cable was there stretched upon the ice in a loop of about 8 square kilometers, and connected through a very sensitive galvanometer. The observations of Dr. Giese show that the deflections of the galvanometer correspond to the variations of the Lloyd balance, and also to the vertical component, whereby the conclusion is permitted that the disturbance of the galvanometer was controlled by the current in the loop, which was induced by the changes in the vertical component.

It is clear that the experiment can be altered in such a way that it may extend to a great solenoid reaching through a great circle. This consideration leads inevitably to the thought of investigating by similar observations the two other components, and also the total intensity. For this last it will be necessary for one to have a solenoid with its axis in the direction of the inclination needle, and, furthermore, it must be worth considering whether this observation can be

[1] Vol. I, append., p 21.

made in a cable which surrounds the whole body of the earth. For the installation of such inductions observations in a solenoid, points of view could be mentioned which are not unimportant. Since the indirect current in circuits or solenoids is dependent upon the quickness of the change of corresponding magnetic elements, there exists by means of them a method of magnifying the intensity of very small but perceptible changes. A further significance is derived from these observations of the induction current for the knowledge of the earth currents. The comparison of corresponding induced currents with the currents in solenoids will show whether the first are related natural or induced currents. Even with a negative result an advantage would be gained, and at least the direction be found in which further investigations should be undertaken. The fact that the observations of earth currents, since their discovery, has given only a few conclusions seems to indicate that the previous methods of observations are insufficient, and we must, in the first place, direct our attention to the improvement of the same.

## 10.—THE PRESENT CONDITION OF MATHEMATICAL ANALYSIS AS APPLIED TO TERRESTRIAL MAGNETISM.

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### I.—INTRODUCTORY DISCUSSION.

The three components of magnetic force which may be observed at any point of the earth's surface, may be represented either by graphical or by analytical methods. The former, if adopted, gives us the usual magnetic charts, while the latter yields a certain mathematical expression. The advantage of the analytical method, which forms the subject of this paper, lies in the fact that we may deduce from it important conclusions concerning the origin of the magnetic forces. The best method of mathematical analysis deserves a careful investigation independently of any use which might be made of its results, but it is essential to bear in mind that our analytical reductions are only a means to an end. If we do not wish to pursue that end the graphical method will give us, with less trouble, a better picture of the results of observation.

It will be necessary to say a few words in the first place about the functions which will have to form the basis of our calculations. We define $P_n$ as a zonal surface harmonic of degree $n$, if

$$P_n=\frac{1}{2^n n!}\frac{d^n}{d\mu^n}(\mu^2-1)^n$$

where $\mu$ is the cosine of the colatitude.[1]

[1] I shall follow, as far as possible, the notation and nomenclature adopted in "Ferrer's Spherical Harmonics." It will not be possible to enter into any historical discussion concerning this nomenclature. Information on many points important to the physicist will be found in "Maxwell's Electricity and Magnetism," and "Thompson and Tait' Natural Philosophy."

If the differentiation is performed and the terms arranged according to powers of $\mu$ the following series is obtained:

$$P_n=\frac{1.3.5\dots(2n-1)}{1.2.3\dots\ \ n}\left[\mu^n-\frac{n(n-1)}{2(2n-1}\mu^{n-2}+\frac{n(n-1)(n-2)(n-3)}{2.4.(2n-1)(2n-3)}\mu^{n-4}\dots\right]$$

We denote by the symbol $T_n^\sigma$ that function of $\mu$ which is defined by

$$T_n^\sigma=(1-\mu^2)^{\frac{\sigma}{2}}\frac{d^\sigma P_n}{d\mu^\sigma},$$

and following the nomenclature of Thompson and Tait we shall call the functions cos. $\sigma\lambda\ T_n^\sigma$ and sin. $\sigma\lambda\ T_n^\sigma$ tesseral harmonics of degree $n$ and type $\sigma$, where $\lambda$ is the longitude measured from a fixed meridian circle.

It can be proved that $T_n^\sigma$ vanishes for $n-\sigma$ different values of $\mu$, and as cos. $\sigma\ \lambda$ and sin. $\sigma\ \lambda$ vanish on $2\sigma$ meridian circles, a spherical surface is divided into $2\sigma(n-\sigma-1)$ quadrilaterals or "tesseræ" and $4\sigma$ triangles at the poles, by the circles on which the tesseral harmonic vanishes. When $n$ is equal to $\sigma+1$ there will be no tesseræ and when $n$ is equal to $\sigma$ the harmonic will vanish only on $\sigma$ meridian circles, and is then called a sectorial harmonic.

The following expression for $T_n^\sigma$ may be useful:

$$T_n^\sigma=\frac{2n\,(2n-1)\dots.(n-\sigma+1)}{2^n\,n\,!}(1-\mu^2)^{\frac{\sigma}{2}}\left[\mu^{n-\sigma}-\frac{(n-\sigma)(n-\sigma-1)}{2\,(2n-1)}\mu^{n-\sigma-2}\right.$$
$$\left.+\frac{(n-\sigma)\,(n-\sigma-1)\,(n-\sigma-2)\,(n-\sigma-3)}{2\qquad 4\qquad (2n-1)\,(2n-3)}\mu^{n-\sigma-4}-\dots\right]$$

If $\sigma=n$ this becomes

$$T_n^n=\frac{2n\,(2n-1)\,(2n-2)\dots.(n+1)}{2^n}(1-\mu^2)^{\frac{n}{2}}$$

or a function of sin. $\theta$ if $\theta$ is the colatitude.

The zonal harmonic is obtained by putting $\sigma=0$ in the expression for the tesseral harmonic. The zonal, tesseral, and sectorial surface harmonics are jointly called spherical surface harmonics. These properties are such as to render them thus of special importance in many problems of mathematical physics, and especially in the domain of terrestrial magnetism.

Any functions of two varieties $\lambda$ and $\mu$ may if $\lambda$ varies between 0 and $2\pi$ and $\mu$ between $+1$ and $-1$ be expanded in a series of tesseral harmonics. If we take two diametrically opposite points on a sphere as poles, any quantity which has given values over the surface of the sphere can be expressed in terms of the longitude and latitude referred to the poles chosen, and can therefore be expanded into a series of surface harmonics. The poles are arbitrary, but in the case of any expansion having reference to the surface of the earth it is obviously convenient to choose the earth's geographical poles as poles of the harmonics.

Should it ever become desirable to take account of the spheroidal shape of the earth, there would be no theoretical difficulty. The spherical harmonics would have to be replaced by "spheroidal" harmonics or Lamé's functions, but for our present purpose it will be sufficient to consider the earth as a sphere.

The fundamental proposition which enables us to expand any given function into a series of harmonics is expressed by the equation

$$\int_{-1}^{+1}\int_{0}^{2\pi} Y_l\, Y_m\, d\mu\, d\lambda = o$$

where $Y_l\, Y_m$ represent any two surface harmonics differing either in degree or type.

If the two surface harmonics are of the same degree and type they must contain the same function of $\mu$ and the above equation is replaced by one of the following where $dS$ stands for the element of surface and $a$ is the radius of the sphere.

$$\int\left[T_n^\sigma \cos. \sigma\lambda\right]^2 dS = \frac{(n+\sigma)!}{(n-\sigma)!}\,\frac{2\pi\, a^2}{(2n+1)}$$

$$\int\left[T_n^\sigma \sin. \sigma\lambda\right]^2 dS = \frac{(n+\sigma)!}{(n-\sigma)!}\,\frac{2\pi\, a^2}{(2n+1)}$$

$$\int\left[T_n^\sigma\right]^\sigma \sin. \sigma\lambda \cos. \sigma\lambda\, dS = o$$

The equations can not be applied if $\sigma = o$. In that case

$$\int\left[P_n\right]^2 dS = \frac{4\pi\, a^2}{2n+1}$$

that is to say, the surface integral is double what it would be if in the first of the above equations $\sigma$ is put equal to $o$. When $n = \sigma$ the product $(n - \sigma)!$ must be replaced by unity.

We shall not attempt to prove the possibility of the expansion of any arbitrary function in terms of a series of harmonics, but assuming the expansion to be possible, proceed to show how the coefficients may be determined. Let $A_n^\sigma$ and $B_n^\sigma$ be the coefficients of the two tesseral harmonics of type $\sigma$ and degree $n$, so that we may write

$$F(\mu, \lambda) = \sum_{\sigma=0}^{\sigma=n} A_n^\sigma\, T_n^\sigma \cos. \sigma\,\varphi + \sum_{\sigma=0}^{\sigma=n} B_n^\sigma\, T_n^\sigma \sin. \sigma\,\varphi$$

Multiply both sides of the equation with $T_n^\sigma \cos. \sigma\varphi$ and integrate over the surface of the sphere, the surface integrals will all vanish except those depending on the square of $T_n^\sigma \cos. \sigma\varphi$ and hence

$$\int F(\mu, \lambda)\,(T_n^\sigma \cos. \sigma\varphi)\, dS = \frac{(n+\sigma)!}{(n-\sigma)!}\,\frac{2\pi}{(2n+1)}\, A_n^\sigma$$

except when $\sigma = o$, and in that case

$$\int F(\mu, \lambda) P_n\, dS = \frac{4\pi}{2n+1}\, A_n^0$$

Hence the coefficients of the expansion are determined as surface integrals by the equations—

$$A^{\circ}_{n} = \frac{2n+1}{4\pi}\int F(\mu,\lambda)\, P_{n}\, dS$$

$$A^{\sigma}_{n} = \frac{2n+1}{2\pi}\,\frac{(n-\sigma)!}{(n+\sigma)!}\int F(\mu,\lambda)\, T^{\sigma}_{n} \cos.\sigma\varphi\, dS,$$

with the corresponding equation

$$B^{\sigma}_{n} = \frac{2n+1}{2\pi}\,\frac{(n-\sigma)!}{(n+\sigma)!}\int F(\mu,\lambda)\, T^{\sigma}_{n} \sin.\sigma\varphi\, dS.$$

By means of these equations we might represent in a series any of the magnetical variables, as, for instance, the horizontal force, the total intensity, the declination, etc.

The question arises which particular quantity to choose, and it is found that the analytical expression for the magnetic potential is of special importance. Not only may all other quantities depending on the magnetic forces be derived from the magnetic potential, but, as pointed out by Gauss, the proper expression of the magnetic potential will allow us to discriminate between magnetic forces due to causes outside and those due to causes inside the earth. Imagine the surface potential to contain a term

$$A^{\sigma}_{n}\, T^{\sigma}_{n} \cos.\sigma\lambda.$$

It follows from the general theory of forces varying as the inverse square of the distance that the value of the potential near the surface of the earth will, as far as that term is concerned, be

$$A^{\sigma}_{n}\, T^{\sigma}_{n} \cos.\sigma\lambda \frac{a^{n+1}}{r^{n+1}}$$

if the magnetic forces are due entirely to causes inside the earth, but that if the causes be outside, the expression will become

$$A^{\sigma}_{n}\, T^{\sigma}_{n} \cos.\sigma\lambda \frac{r^{n}}{a^{n}}$$

The earth's radius in these equations is denoted by $a$, while $r$ is the distance from the earth's center. The observed vertical force will show whether either of these expressions represents the facts or whether the forces are partly due to one cause and partly due to another.

Assuming the existence of both causes, we have for the potential near the earth, a series of terms of the form

$$\left[L^{\sigma}_{n} \frac{a^{n+1}}{r^{n+1}} + M^{\sigma}_{n} \frac{r^{n}}{a^{n}}\right] T^{\sigma}_{n} \cos.\sigma\varphi$$

where $L^{\sigma}_{n}$ and $M^{\sigma}_{n}$ are two constants.

Let $Z$ be the vertical force counted positive if acting upward, so that, $V$ being the potential,

$$Z = -\frac{dV}{dr}.$$

Let the vertical force be expanded independently into a series of surface harmonics, $Z_n^\sigma$ being the coefficient multiplying the term of type $\sigma$ and degree $n$. By differentiation of the potential with respect to $r$, and taking $r = a$, we obtain

$$a\,Z_n^\sigma = n\,M_n^\sigma - (n+1)\,L_n^\sigma$$

while the expansion of the potential gives us for $r = a$

$$A_n^\sigma = M_n^\sigma + L_n^\sigma$$

The last two equations are sufficient to determine $M_n^\sigma$ and $B_n^\sigma$ if $Z_n^\sigma$ and $A_n^\sigma$ are known.

We shall have to discuss the methods of obtaining the coefficients $A_n^\sigma$ and $B_n^\sigma$. The problem is complicated by the fact that we do not directly observe the magnetic potential, but its derivatives, and we begin by giving a short account of the attempts which have so far been made to obtain numerical values for the coefficients.

## II.—GAUSS'S METHOD OF OBTAINING THE COEFFICIENTS IN THE HARMONIC ANALYSIS OF THE MAGNETIC POTENTIAL.

Gauss, whose treatise on the subject merits careful study, assumes in his numerical calculation that the seat of the magnetic forces is inside the earth. He takes, as basis of his calculation, the values of the magnetic forces at 84 points which lie on the intersections of 12 longitude and 7 latitude circles. The three components of the forces give him, therefore, 252 observed quantities. We take $X$, $Y$, $Z$, to be the three components of magnetic force connected with the potential by means of the equations

$$X = -\frac{dV}{ad\theta} = \sqrt{1-\mu^2}\,\frac{dV}{ad\mu}; \quad Y = \frac{-1}{\sqrt{1-\mu^2}}\,\frac{dV}{ad\lambda}; \quad Z = -\frac{dV}{dr},$$

in which $\lambda$ is the longitude toward geographical west and $\mu$ the cosine of the colatitude. For each latitude circle we may express the three components of force by a well-known method in terms of a series of sines and cosines of the form

$$\begin{aligned} X &= X^\circ + X' \cos.\lambda + \mathsf{X}' \sin.\lambda + X'' \cos.2\lambda + \mathsf{X}'' \sin.2\lambda + \ldots \\ Y &= Y^\circ + Y' \cos.\lambda + \mathsf{Y}' \sin.\lambda + Y'' \cos.2\lambda + \mathsf{Y}'' \sin.2\lambda + \ldots \\ Z &= Z^\circ + Z' \cos.\lambda + \mathsf{Z}' \sin.\lambda + Z'' \cos.2\lambda + \mathsf{Z}'' \sin.2\lambda + \ldots \end{aligned} \qquad \text{(I)}$$

The *series* coefficients $X'$, $Y'$, $Z'$, etc., are different for each latitude

circle, and we may take them to be functions of $\mu$, the numerical values of which are known at definite points.

The series for $V$ assuming only internal magnetic forces takes the form

$$\frac{V}{a} = A_1^0 \ P_1 \frac{a^2}{r^2} + A_2^0 P_2 \frac{a^3}{r^3} + A_3^0 P_3 \frac{a^4}{r^4}$$

$$+\cos.\lambda\left[A_1^1 \ T_1^1 \frac{a^2}{r^2} + A_2^1 \ T_2^1 \frac{a^3}{r^3} + \ldots\right.$$

$$+\sin.\lambda\left[B_1^1 \ T_1^1 \frac{a^2}{r^2} + B_2^1 \ T_2^1 \frac{a^3}{r^3} + \ldots\right.$$

$$+\cos.2\,\lambda\left[A_2^2 \ T_2^2 \frac{a^3}{r^3} + A_3^2 \ T_3^2 \frac{a^4}{r^4} + \ldots\right.$$

$$+\sin.2\,\lambda\left[B_2^2 \ T_2^2 \frac{a^3}{r^3} + \ldots\right.$$

From this series we may obtain by differentiation expressions for $X$, $Y$, $Z$, and putting $r = a$ these expressions must agree with the set of equations (I).

The coefficients of cos. $\lambda$, sin. $\lambda$, etc., of the two sets may be equated to each other, and we thus obtain another set of equations of which the following three may be taken as a type:

$$-X' = A_1^1 \frac{dT_1^1}{d\theta} + \frac{A_2^1 \, dT_2^1}{d\theta} + \frac{A_3^1 \, dT_3^1}{d\theta}$$

$$Y' = A_1^1 \ \frac{T_1^1}{\sqrt{1-\mu^2}} + A_2^1 \ \frac{T_2^1}{\sqrt{1-\mu^2}} + A_3^1 \ \frac{T_3^1}{\sqrt{1-\mu^2}}$$

$$Z' = 2\,A_1^1 \ T_1^1 + 2\,A_2^1 \ T_2^1 + 2\,A_3^1 \ T_3^1$$

All equations which contain any of the coefficients $A_n^1$ are included and we shall have seven such sets if we take, as Gauss did, seven latitude circles for which $X'$, $Y'$, $Z'$, have been calculated. There will be 21 equations to calculate the coefficients $A_n^1$ the quantities $T_1^1$, $T_2^1$, $\frac{dT_1^1}{d\theta}$ etc., having known values for each latitude circle.

Gauss neglected all terms of a degree higher than the fourth; and calculated the four coefficients $A_1^1$, $A_2^1$, $A_3^1$, $A_4^1$, with the help of 21 equations by the method of least squares. There are altogether $(2i+1)$ coefficients of degree $i$, and the number of harmonics of all degrees up to and including $i$ will be $i\,(i+2)$. Taking account therefore of the terms of different types Gauss had to calculate 24 coefficients; that is to say 4 belonging to the zonal harmonics, 8 belonging to the harmonics of the first type, 6 to the second type, 4 to the third type, and 2 to the fourth type.

The values of the coefficients as found by Gauss will be given in Table I.

In order to judge how far the magnetic components calculated by means of the harmonic series truly represent the actual forces, Gauss compared the observed with the calculated elements at a great number of stations. Looking over the table of comparison given by him, we find that the average difference between the calculated and the observed values of declination is about 1° in the Northern Hemisphere, but the agreement in the Southern Hemisphere is not so good. The total intensity generally comes within 4 per cent of the observed value in the Northern Hemisphere.

An attempt to improve on Gauss's value of the constants was made by Petersen under Ermann's superintendence. The British Association granted a sum of money toward the purpose and the results are published in the Reports of the Association for 1848. (See also *Astronomische Nachrichten* Nos. 1792, 1793, 1870.) Petersen's values for the constants are given in column III of Table I.

It will be seen that the difference between them and those deduced by Gauss are most important. In fact, except as regards the first coefficients, there is no similarity between the values obtained. In order to judge which of the two sets should have the greater weight, we must bear in mind one important consideration. In order that the coefficients of the various harmonics of a series should be determinate, it is necessary that the quantity to be expanded should be known at all points of the spherical surface. Thus, if the potential was known at every point of the earth's surface, with the exception of a region which may be as small as we like, then, theoretically, every coefficient of the expansion is completely indeterminate. If practically we are able to calculate the coefficients, it is only because experience teaches us that there are no violent and sudden changes in the earth's magnetic forces when we pass from one point to another point near it.

Only in so far as a great number of observations, taken at different points of the earth, allow us to predict approximately what the magnetic component at every other point would be, in so far may we trust to these observations to help us in the representation of the potential by means of a series. Gauss, in his original work, took, as already stated, 12 evenly distributed points on each of seven latitude circles. His 108 points were, therefore, distributed pretty evenly over the whole globe, and we must attach a weight to his final result depending only on the degree of accuracy of the numbers taken as his basis of calculation. Petersen's numbers, on the other hand, were those obtained by Ermann in a journey around the world. These were obtained, as explained by him (Report British Association, 1846), "at about 650 equidistant stations on a line encircling the globe be-

tween latitudes 67° N. and 60° S." Now, it is quite clear that observations taken in this way, however numerous they may be, can not give us any information on the magnetic forces at places situated off the particular track of the route, and, taken by themselves, such observations are totally insufficient as a foundation for a reduction according to the harmonic analysis. In spite of the enormous labor bestowed on the work by Mr. Petersen, we can not attach any value to his results.

TABLE I.—*Values of the coefficients in the expression of the magnetic potential of the earth in a series of spherical harmonics.*

The numbers refer to a period near 1880.

The longitude is reckoned from Greenwich toward the east.

In order to reduce the numbers to C. G. S. measure, they must be multiplied with .000849.

The decimal places, given in the original papers, are omitted.

| Coefficients. | Gauss. | Petersen. | Difference. |
|---|---|---|---|
| | | | *P—G.* |
| $A_1^0$ | +926 | +845 | − 81 |
| $A_2^0$ | − 22 | +104 | +126 |
| $A_3^0$ | − 19 | − 70 | − 52 |
| $A_4^0$ | −109 | −176 | − 67 |
| $A_1^1$ | + 89 | + 34 | − 55 |
| $A_2^1$ | −145 | 0 | +145 |
| $A_3^1$ | +123 | − 27 | −150 |
| $A_4^1$ | −153 | −143 | + 10 |
| $B_1^1$ | −179 | −168 | + 10 |
| $B_2^1$ | − 6 | −100 | − 94 |
| $B_3^1$ | + 48 | +230 | −183 |
| $B_4^1$ | + 64 | − 95 | −159 |
| $A_2^2$ | 0 | − 11 | − 11 |
| $A_3^2$ | − 73 | − 9 | + 64 |
| $A_4^2$ | − 46 | −176 | −130 |
| $B_2^2$ | − 39 | − 87 | − 48 |
| $B_3^2$ | − 23 | +122 | +145 |
| $B_4^2$ | + 43 | − 95 | −137 |
| $A_3^3$ | + 1 | + 39 | + 38 |
| $A_4^3$ | + 20 | − 45 | − 65 |
| $B_3^3$ | − 19 | − 40 | − 21 |
| $B_4^3$ | 0 | + 36 | − 37 |
| $A_4^4$ | + 4 | + 20 | + 16 |
| $B_4^4$ | + 3 | + 8 | + 5 |

## III.—NEUMANN'S METHOD OF OBTAINING THE COEFFICIENTS.

The discussion as to the most appropriate method to proceed in any future attempt to solve our problem divides itself into two parts. The first refers to the method of expansion of a given function into a series of spherical harmonics, the second to the complication arising from the fact that we do not directly observe the potential, but only its derivatives. With regard to the first point, we must refer to a proposal of Dr. Franz Neumann, an account of which is given in his *Vorlesungen über die Theorie des Potentials und der Kugelfunctionen.*

Let the function $F(\mu\lambda)$ be known at the points of intersection of $2p$ equidistant meridian circles and 9 circles of latitude. For each of the latitude circles we may obtain in the usual way an equation of the form

$$\begin{aligned} F(\mu, \lambda) = C_0 + C_1 \cos. \lambda + C_2 \cos. 2\lambda + C_3 \cos. 3\lambda + \ldots . \; & C_p \cos. p\lambda \\ + S_1 \sin. \lambda + S_2 \sin. 2\lambda + \ldots . \qquad\qquad & S_p \sin. p\lambda. \end{aligned}$$

In what follows we shall omit the terms containing the sines; they may easily be supplied by symmetry whenever they are required.

The series contains $2p+1$ coefficients, but as $\sin. p\lambda$ will vanish at all given points $S_p$ remains undetermined. The remaining $2p$ coefficients may be calculated from the $2p$ points for which the function is known. These coefficients may then be considered as known, and we may take them to represent for each latitude circle the known values of the function. If the above series is compared with the general equation representing the expansion into spherical harmonics and the coefficients of $\cos. \lambda$, $\cos. 2\lambda$, etc., are equated to each other, we obtain a further set of equations

$$\begin{array}{llllll}
C_0 = & A_0 T_0^0 + A_1^0 T_1^0 + & A_2^0 T_2^0 + \ldots . & A_j^0 T_j^0 + \ldots . & A_p^0 T_p^0 \\
C_1 = & A_1^1 T_1^1 + & A_2^1 T_2^1 + & A_j^1 T_j^1 + & A_p^1 T_p^1 \\
C_2 = & & A_2^2 T_2^2 + & A_j^2 T_j^2 + & A_p^2 T_p^2 \\
\ldots . & & & \ldots & \ldots . \\
\ldots . & & & \ldots . & \ldots . \\
\ldots . & & & \ldots . & \ldots . \\
C_j = & & & A_j^j T_j^j & A_p^j T_p^j \\
\ldots . & & & \ldots . & \ldots . \\
\ldots . & & & \ldots . & \ldots . \\
\ldots . & & & \ldots . & \ldots . \\
C_p = & & & & A_p^p T_p^p
\end{array}$$

Each latitude circle will furnish us with a separate set of such equations. Defining these different circles by $\mu_1$, $\mu_2$, etc., a set of equations containing the coefficients $C_j$ will be

$$C_j(\mu_1)=A^j_j\,T^j_j(\mu_1)+A^j_{j+1}\,T^j_{j+1}(\mu_1)+\ldots A^j_k\,T^j_k(\mu_1)+\ldots.A^j_p\,T^j_p(\mu_1)$$
$$C_j(\mu_2)=A^j_j\,T^j_j(\mu_2)+A^j_{j+1}\,T^j_{j+2}(\mu_2)+\ldots A^j_k\,T^j_k(\mu_2)+\ldots.A^j_p\,T^j_p(\mu_2)$$
$$\begin{array}{ccccc} \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots \end{array}$$
$$C_j(\mu_q)=A^j_j\,T^j_j(\mu_q)+A^j_{j+1}\,T^j_{j+1}(\mu_q)+\ldots A^j_k\,T^j_k(\mu_q)+\ldots.A^j_p\,T^j_p(\mu_q)$$

This gives us 9 equations to determine the $p+j-1$ coefficients. So far the process is identical with that adopted by Gauss, but while Gauss would solve the last set of equations by the method of least squares, Neumann abandons that method and obtains the solution in a simpler form. In order to obtain, for instance, the coefficient $A^j_k$ let the first equation be multiplied by $a_1\,T^j_k(\mu_1)$, the second by $a_2\,T^j_k(\mu_2)$, etc., and add up the equations formed in this way. Neumann shows that the coefficients $a_1$, $a_2$, $a_3$ may always be chosen so that the sum is

$$\sum_{s=1}^{s=q} a_s\,T^j_k(\mu_s)\,T^j_p(\mu_s)=\frac{2}{2k+1}\,\frac{(k+j)\,!}{(k-j)\,!}\text{ or } o$$

according as $p$ is equal to $j$ or not. In the special case $k=j$, $(k-j)\,!$ is to be replaced by unity. The sum of all the equations obtained as explained will therefore give

$$\sum_{s=1}^{s=q} a_s\,C_j(\mu_s)T^j_k(\mu_s)=\frac{2}{2k+1}\,\frac{(k+j)\,!}{(k-j)\,!}\,.\,A^j_k.$$

The coefficients $A^j_k$ are therefore determined in a simple way, provided that the coefficients $a_1\,a_2\ldots.$, are known. Neumann shows how to determine them in two special cases, but it is not needful for our purpose to enter into this question. There is one consideration which would seem at first sight fatal to Neumann's method of procedure. In solving a number of equations greater than the unknown quantities, the method of least squares is the only one which will satisfy the equations in the best possible manner. It is obvious that simplicity of solution is not a safe guide to trust to, for we might combine the equations with each other so as to give results which do not even approximately represent the best values of the unknown quantities. Neumann's method is equivalent to attaching certain weights $a_1$, $a_2$, $a_3$, etc., to each of his original equations; there seems no reason given why more value should be given to one equation than to another, and it even appears that in some cases the weights are negative. Neumann has not, as far as I know, properly justified his method. Nevertheless, it will appear that we shall be led to the same method independently by another line of reasoning, which seems

more consistent with the first principles of spherical harmonic analysis.

## IV.—DISCUSSION OF THE MOST SUITABLE METHOD TO BE ADOPTED IN FUTURE REDUCTIONS.

We are now prepared to discuss the most suitable method to be applied in future. There are two objections to the procedure adopted by Gauss. Firstly, the vertical forces should not be used together with the horizontal forces in the development of the series, but should be treated separately. Secondly, the value of the coefficients multiplying the harmonics of different degrees are made to depend on each other. Thus the value of the coefficient multiplying the zonal harmonic of the first degree is made to depend on the question whether the zonal harmonic of the fourth degree is taken into consideration or not. We shall show that this difficulty can be obviated by obtaining two separate series, one for the northerly and one for the westerly forces. The terms which are of cosmical importance are those of the first two types and degrees, and we may hope to push the subject more forward by spending time and trouble over the first few coefficients than by an attempt to calculate a great number of them. From the nature of the analysis the coefficients are independent, and we should be able, therefore, to calculate them independently. If the function which is to be expanded is the one to which our observations apply directly, the coefficients of the series are obtained in the most natural way by going back to the fundamental equation for these coefficients:

$$A_n^\sigma = \frac{(2n+1)}{2\pi a^2}\,\frac{(n-\sigma)\,!}{(n+\sigma)\,!}\int F(\mu,\lambda)\,T_n^\sigma \cos.\sigma\lambda\, dS.$$

Writing $dS = a^2\, d\mu\, d\lambda$, we have first to perform the integration

$$\int_0^{2\pi} F(\mu,\lambda)\cos.\sigma\lambda.\,d\lambda$$

but this integral is the coefficient of $\cos.\sigma\lambda$ in the expansion of $F(\mu,\lambda)$ multiplied with $\pi$. Calling this coefficient $C_\sigma$, the equation for $A_n^\sigma$ will become

$$A_n^\sigma = \frac{2n+1}{2}\,\frac{(n-\sigma)\,!}{(n+\sigma)\,!}\int_{-1}^{+1} C_\sigma\, T_n^\sigma\, d\mu.$$

The values of $C_\sigma\ T_n^\sigma$ are functions of $\mu$, supposed to be known over a certain number of latitude circles, and the problem is, therefore, that of finding $\int_{-1}^{+1} y\,dx$, where $y$ is given for a number of values of $x$. That is a well-known problem. If $a_1$, $a_2$, $a_3$, are coefficients which depend on the distribution of the values for which $y$ or, in our case, $C_s\ T_n^\sigma$, are known, the integral is approximately

represented by the sum

$$\sum_{s=1}^{s=p} a_s C_\sigma(\mu_s)\, T^\sigma_n(\mu_s)$$

where $C_\sigma(\mu_s)$ and $T^\sigma_n(\mu_s)$ stand for those particular values which the quantities $C_\sigma$ and $T^\sigma_n$ take on the latitude circles $\mu_s$.

We therefore arrive at the final expression for $A^\sigma_n$

$$A^\sigma_n = \frac{2n+1}{2}\,\frac{(n-\sigma)!}{(n+\sigma)!}\sum_{s=1}^{s=p} a_s C_\sigma(\mu_s)\, T^\sigma_n \mu_s$$

But this is exactly the value of $A^\sigma_n$, given by Neumann, the values of $a_s$, agreeing with those given by him, and is the most direct and natural expression.

The values of the coefficients $a_s$ depend on the distribution of the circles of latitude for which the function to be expanded is supposed to be known. If we chose our latitude circles so that the values of $\mu$ proceed in arithmetical progression, the values of $a$ will be those given by Newton and Cotes. On the other hand, the most favorable distribution of $n$ circles of latitude is that in which the $\mu$ are the roots of the zonal harmonic $P_n(\mu)$. In the actual calculation of the coefficients it would not probably be necessary to obtain accurate values for the coefficients. All we have to insure is that the integral $\int_{-1}^{+1} y\,dx$ is evaluated with sufficient accuracy, from a certain number of known values of $y$. It will only be possible to decide the simplest method of doing this when we have an actual case before us.

It remains to be shown how we may obtain the series for the potential from the observations of the horizontal components.

If $Y$ is the force toward geographical west and $u$ the colatitude,

$$Y \sin. u = \frac{dV}{a d\lambda}$$

If, therefore, $Y$ be expressed in a series,

$$Y \sin. u = \sum_{\sigma=1}^{\sigma=\infty} C^\sigma_n T^\sigma_n \cos. \sigma\lambda + \sum_{\sigma=1}^{\sigma=\infty} S^\sigma_n T^\sigma_n \sin. \sigma\lambda,$$

we obtain by integration,

$$V/a = \sum_{\sigma=1}^{\sigma=\infty} \frac{1}{\sigma} C^\sigma_n T^\sigma_n \sin. \sigma\lambda - \sum_{\sigma=1}^{\sigma=\infty} \frac{1}{\sigma} S^\sigma_n T^\sigma_n \sin. \sigma\lambda + f(\mu).$$

Comparing this with the expansion of $V$ in the form,

$$V/a = \sum_{\sigma=0}^{\sigma=\infty} A^\sigma_n T^\sigma_n \cos. \sigma\lambda + \sum_{\sigma=0}^{\sigma=\infty} B^\sigma_n T^\sigma_n \sin. \sigma\lambda$$

we may determine all coefficients, $A$ or $B$, with the exception of those of type zero, for

$$A^\sigma_n = -\frac{1}{\sigma} S^\sigma_n \quad \text{and} \quad B^\sigma_n = \frac{1}{\sigma} C^\sigma_n,$$

whenever $\sigma$ is equal to or greater than unity.

The west force, as is well known, can not give us any information in the terms of zero type, that is to say, on the zonal harmonics. These must be entirely obtained from the force toward geographical north, and, as we proceed to show, this may be done easily. Let the force toward geographical north, for the different latitude circles, be expanded in a series,

$$K_0 + K_1 \cos. \lambda + \dots.$$

The zonal harmonics can only depend on the values of $K_0$, which is easily found by well known methods. This quantity $K_0$, being now given on a series of latitude circles, may be expanded into a series of the following form:

$$K_0 = H_1 \sin. u. \frac{dP_1}{d\mu} + H_2 \sin. u \frac{dP_2}{d\mu} + H_3 \sin. u \frac{dP_3}{d\mu} + \dots.$$

But as from the general equation

$$X = \frac{1}{a}\frac{dV}{du} = -\frac{1}{a}\frac{dV}{d\mu} . \sin. u$$

it follows that as far as the zonal harmonics are concerned

$$-\frac{V}{a} = H_1 P_1 + H_2 P_2 + \cdots$$

which gives the required series.

Although the above method would be sufficient to give us all the required coefficients, it will be seen that we have only made use of the northerly force to determine the zonal harmonics, while the tesseral harmonics are made solely to depend on the westerly force. It is evidently desirable, in order to make the greatest use of all observations, to determine, if possible, the coefficients of the tesseral harmonics, independently from the $X$ and $Y$ components of force.

We deduce, in the first place, a general equation which will be required for our purpose.

We start from the relation

$$(2i+1)\mu P_i = (i+1) P_{i+1} + i P_{i-1}$$

and differentiate $n$ times with respect to $\mu$; we obtain thus

$$(2i+1)\mu \frac{d^n P_i}{d\mu^n} = (i+1-n)\frac{d^n P_{i+1}}{d\mu^n} + (i+n)\, d^n P_{(i-1)}$$

For the differential coefficient of the function $T^\sigma_i$ we obtain

$$\frac{d}{d\mu} T^\sigma_i = \frac{d}{d\mu}(i-\mu^2)^{\frac{\sigma}{2}} \frac{d^\sigma P_i}{d\mu^\sigma} = (1-\mu^2)^{\frac{\sigma}{2}} \frac{d^{\sigma+1} P_i}{d\mu^{\sigma+1}} - \sigma\mu(1-\mu^2)^{\frac{\sigma-2}{2}} \frac{d\sigma P_i}{d\mu^\sigma}.$$

Hence

$$(2i+1)(1-\mu^2)\frac{d}{d\mu} T^\sigma_i = (2i+1)(1-\mu^2)^{\frac{1}{2}} T^{\sigma+1}_i$$

$$- (2i+1)\sigma\mu(1-\mu^2)^{\frac{\sigma}{2}} - \frac{d\sigma_i P_i}{d\mu^\sigma}.$$

Substituting for $(2i+1)\ \mu\frac{d^\sigma P_i}{d\mu^\sigma}$ its value as given above

$$(2i+1)(1-\mu^2)\frac{d}{d\mu}T_i^\sigma = (2i+1)(1-\mu^2)^{\frac{1}{2}}T_i^{\sigma+1} - \sigma(i+1-\sigma)T_{i+1}^\sigma$$
$$-\sigma(i+\sigma)\ T_{i-1}^\sigma$$

We may also easily find

$$(2i+1)(1-\mu^2)^{\frac{1}{2}}T_i^{\sigma+1} = (i-\sigma)(\sigma-i-1)T_{i+1}^\sigma + (i+\sigma)(i+1+\sigma)T_{i-1}^\sigma$$

Hence

$$(2i+1)(1-\mu^2)\ \frac{d}{d\mu}T_i^\sigma = i\ (\sigma-i-1)T_{i+1}^\sigma + (i+\sigma)(i+1)T_{i-1}^\sigma.$$

This equation has been given without proof by Mr. Ad. Schmidt in a communication to the International Polar Commission in 1886.

Let the value of $X$ sin. $u = X\sqrt{1-\mu^2}$ be expanded in a series of the form

$$X\sin.u = \sum_{\sigma=0}^{\sigma=\infty} E_n^\sigma\ T_n^\sigma \cos.\sigma\lambda + \sum_{\sigma=0}^{\sigma=\infty} F_n^\sigma\ T_n^\sigma \sin.\sigma\lambda$$

the potential being as before

$$V/a = \sum_{\sigma=0}^{\sigma=\infty} A_n^\sigma\ \ T_n^\sigma \cos.\sigma\lambda + \sum_{\sigma=0}^{\sigma=\infty} B_n^\sigma\ T_n^\sigma \sin.\sigma\lambda$$

As far as the coefficients $A_n^\sigma$ are concerned, we find

$$\frac{X}{\sin.u} = \frac{dV}{ad\mu} = A_n^\sigma \frac{dT_n^\sigma}{d\mu}\cos.\sigma\lambda$$

Hence

$$X\sin.u = A_n^\sigma(1-\mu^2)\frac{dT_n^\sigma}{d\mu}\cos.\sigma\lambda$$

$$= \frac{A_n^\sigma}{2n+1}\left[n\ (\sigma-n-1)T_{n+1}^\sigma + (n+\sigma)(n+1)\ \ T_{n-1}^\sigma\right]\cos.\sigma\lambda$$

If the sum of the terms on the right-hand side is formed and the coefficient of $T_n^\sigma\cos.\sigma\lambda$ is compared with that determined directly from the expansion of $X$ sin. $u$ we obtain the following set of relations:

$$E_\sigma^\sigma = \frac{(2\sigma+1)(\sigma+2)}{2\sigma+3}A_{\sigma+1}^\sigma$$

$$E_{\sigma+2}^\sigma = \frac{(2\sigma+3)(\sigma+4)}{(2\sigma+7)}A_{\sigma+3}^\sigma - 2\frac{(\sigma+1)}{(2\sigma+3)}A_{\sigma+1}^\sigma$$

$$E_{\sigma+4}^\sigma = \frac{(2\sigma+5)(\sigma+6)}{(2\sigma+11)}A_{\sigma+5}^\sigma - \frac{4\sigma+3}{2\sigma+7}A_{\sigma+1}^\sigma$$

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.... .... ....

and

$$E^{\sigma}_{\sigma+1} = \frac{(2\sigma+2)(\sigma+3)}{(2\sigma+5)} A^{\sigma}_{\sigma+2} - \frac{\sigma A^{\sigma}_{\sigma}}{2\sigma+1}$$

$$E^{\sigma}_{\sigma+2} = \frac{(2\sigma+4)(\sigma+5)}{(2\sigma+9)} A^{\sigma}_{\sigma+4} - \frac{3(\sigma+2)}{2\sigma+5} A^{\sigma}_{\sigma+2}$$

.... .... ....

.... ... ....

.... .... ....

The first set of equations allows us to calculate successively $A^{\sigma}_{\sigma+1}$ and $A^{\sigma}_{\sigma+2}$, etc.; but the second set does not allow us to calculate $A^{\sigma}_{\sigma}$ and $A^{\sigma}_{\sigma+2}$. If we take for the value of $A^{\sigma}_{\sigma}$ that determined by the expansion of $Y \sin. \mu$, the other coefficients may then be determined, but it will be, probably, better to combine together the values of $A^{\sigma}_{\sigma}$ and $A^{\sigma}_{\sigma+2}$, found from $Y \sin. \mu$, with the equation for $E^{\sigma}_{\sigma+1}$, we shall thus have three equations to determine the two coefficients $A^{\sigma}_{\sigma}$ and $A^{\sigma}_{\sigma+2}$.

It will be noticed that the coefficients of the zonal harmonics $E^{0}_{1}$ and $E^{0}_{2}$, etc., are found in a simple way by putting $\sigma = 0$ in the above sets, and, therefore, it will not be necessary; also, it may be convenient to treat these harmonics in the manner which has previously been explained. We have thus come to the conclusion that the expansion of $X \sin. \mu$ and $Y \sin. \mu$ into a series of spherical harmonics will lead, in a simple way, to the series for the potential; and in order to obtain the series for these functions we need not have recourse to the cumbersome method of least squares, but may, by the method of F. Neumann, determine each coefficient separately in a manner involving comparatively little trouble. Before leaving this part of the subject, a few words may be said on the kind of information we may hope to obtain by the analytical treatment. Looking generally at the distribution of magnetic forces on the surface of the earth, we may consider its principal features to be roughly represented by the harmonics of the first degree. If these have been calculated, we may plot down the residual forces and thus discover where the great centers lie which render the surface forces unsymmetrical. Thus we should in this way obtain evidence of any influence due to the distribution of land and water such as, according to Mr. Henry Wilde, account for some marked features in the shape of isogonic lines.

By far the greater part of the magnetic forces observed on the earth are undoubtedly caused by forces below the surface. But there is some doubt as to the origin of the secular variation. I have suggested in my presidential address, delivered last year to Section A of

the British Association, that the secular variation of terrestrial magnetism may be due to electric currents in space induced by the rotation of the earth and the consequent displacement in space of the lines of force due to the earth's magnetism. Further calculations arrived at since then have strengthened my belief in the possibility of such an explanation. If there is any truth in it, the origin of the terms of the first degree and first type, in the development of the potential, ought to be to an appreciable extent external. It seems important to settle this question, and I have already made preparations for a recalculation of the potential, which will decide the question, or if that is not possible, tell us, at any rate, on what part of the earth's surface more accurate determinations of the components of the magnetic forces are required before a settlement may be arrived at.

### V.—THE DIURNAL VARIATION.

The treatment of the diurnal variation presents a different and, in many respects, a simpler problem than the general one which we have so far discussed. The question was first discussed by me in the year 1886 (Phil. Mag., April). In treating of the very small changes involved in the periodic variations we must not assume the existence of a magnetic potential, for there might be conduction or displacement currents crossing the earth's surface. Thus, if there was a periodic change in the electrical surface charge of the earth, such a charge would produce magnetic effects which do not satisfy the condition of a potential. In the paper referred to it was shown that such changes in the variation of the electrical potential as are observed are not sufficient to cause an appreciable magnetic effect, and we have independent evidence that the effects of the diurnal variation are deducible from a magnetic potential. On the other hand, some observations made by Sabine near the magnetic pole would seem to point to discharge currents through the earth's surface, and it would be of the greatest importance to investigate more closely the diurnal variation in the neighborhood of the magnetic pole, in order to confirm or disprove Sabine's results. In my first paper on the subject it was shown that the main feature of the diurnal variation could be expressed by a single term of the harmonic expression, viz:

$$-\frac{V}{a} = \sin. u \cos. u \sin. (t+\lambda).$$

To obtain the potential in space the right hand member should be multiplied either with $\frac{r^2}{a^2}$ or $\frac{a^3}{r^3}$ according as the origin of the term is external or internal. We deduce from this the vertical forces to be according to one hypothesis or the other

$$-\frac{dV}{dr} = \sin. 2u \sin. (t+\lambda) \quad \text{or} \quad -\frac{dV}{dr} = -\frac{3}{2} \sin. 2u \sin. (t+\lambda).$$

Having regard only to the *sign* of the vertical force, it is shown that its changes agree in phase with the hypothesis of an external cause. The more careful investigation since concluded has entirely confirmed this result (Phil. Trans., vol. 180 (A), 1889). For the method of obtaining the potential we may refer to the original paper, and I briefly indicate the results only.

The year chosen for the reduction was 1870, for which complete records exist of the horizontal components of the diurnal variation at Bombay, Lisbon, Greenwich, and St. Petersburg. The vertical components at these stations are also fairly well established at the three first-named observatories.

The daily variation can be represented in a series of the form

$$a_1 \cos. t + b_1 \sin. t + a_2 \cos. 2t + b_2 \sin. 2t, \text{ etc.},$$

where $a_1$ $b_1$, etc., are coefficients and $t$ is the time.

The calculation was carried out as far as the term cos. $4t$ and sin. $4t$, but, owing to the uncertainty of the last few terms, weight is attached only to the first four coefficients; that is to say, to the variations which may properly be called the "diurnal" and semidiurnal" variations. The treatment of each of these two parts is quite independent of the other. As it is known that on each circle of latitude the variations are similar in character and magnitude, also that on the two hemispheres they are symmetrical, the variation was assumed to be known over four circles of latitude passing through the above-mentioned observatories and the four corresponding circles in the Southern Hemisphere. The data was then found sufficient to carry out the calculations with sufficient accuracy. An expression for the potential containing 38 coefficients was then obtained by calculation, and from this expression the diurnal variation of the vertical forces could be found either on the assumption that the disturbing force has its seat inside or that its seat is outside the earth.

The result is established most clearly if we write the vertical force in the form $r_1 \cos. (t - t_1) + r_2 \cos. 2 (t - t_2)$.

Here $r_1$ is the amplitude of the diurnal variation, and $t_1$ the local time at which it has its positive maximum; $r_2$ and $t_2$ are the corresponding quantities for the semidiurnal variation. The only station for which we have complete records for the vertical force in 1870 is Lisbon. It will be seen that the important point in the argument is not so much the amplitude of the oscillation as its phase, which does not vary to any great extent from year to year. As regards the phase, we may, from the continued records of Bombay since 1873, and at Greenwich since 1884, draw conclusions which are sufficient for our purpose. There is greater doubt as to the vertical force variation at St. Petersburg, during 1870, owing to the uncertainty of the temperature correction. The following tables embody the results of the comparison:

*Observed and calculated values of the coefficient $t_1$ and $t_2$ of vertical force when expressed in the form $r_1$ cos. $(t - t_1) + r_2$ cos. $2\ (t - t_2)$ on the supposition that the disturbing force is inside the earth.*

| Place. | Year. | $t_1$. Calculated. | $t_1$. Observed. | $t_1$. Difference. | $t_2$. Calculated. | $t_2$. Observed. | $t_2$. Difference. |
|---|---|---|---|---|---|---|---|
| | | h. m. | h. m. | h. m. | h. m. | h. m. | h. m. |
| Bombay | ...... | 23 02 | 11 13 | + 11 49 | 9 55 | 4 23 | + 5 32 |
| Lisbon | ...... | 22 35 | 10 40 | + 11 58 | 11 42 | 5 50 | + 5 52 |
| Greenwich | 1884 | 22 06 | 8 42 | − 11 57 | 11 32 | 5 56 | + 5 36 |
| St. Petersburg | 1870 | 21 16 | 3 10 | − 5 54 | 10 48 | 7 05 | + 3 43 |
| Do | 1878 | ........... | 7 05 | − 9 49 | ........... | 6 12 | + 4 36 |

*Observed and calculated values of the coefficient $t_1$ and $t_2$ when expressed in the form $r_1$ cos. $(t - t_1) + r_2$ cos. $2\ (t - t_2)$ on the supposition that the disturbing force is outside the earth.*

| Place. | Year. | $t_1$. Calculated. | $t_1$. Observed. | $t_1$. Difference. | $t_2$. Calculated. | $t_2$. Observed. | $t_2$. Difference. |
|---|---|---|---|---|---|---|---|
| | | h. m. | h. m. | h. m. | h. m. | h. m. | h. m. |
| Bombay | ...... | 11 10 | 11 13 | − 0 03 | 3 47 | 4 23 | − 0 36 |
| Lisbon | ...... | 10 37 | 10 40 | − 0 03 | 5 46 | 5 50 | − 0 04 |
| Greenwich | 1884 | 10 03 | 8 42 | + 1 21 | 5 38 | 5 56 | − 0 18 |
| St. Petersburg | 1870 | 8 52 | 3 10 | + 5 42 | 4 38 | 7 05 | − 2 27 |
| Do | 1878 | ........... | 7 05 | − 1 47 | ........... | 6 12 | − 1 34 |

*Observed and calculated values of $r_1$ and $r_2$ in the expression $r_1$ cos. $(t - t_1) + r_2$ cos. $2\ (t - t_2)$ for vertical force.*

| Place. | Year. | $r_1$. Calculated from inside. | $r_1$. Calculated from outside. | $r_1$. Observed. | $r_2$. Calculated from inside. | $r_2$. Calculated from outside. | $r_2$. Observed. |
|---|---|---|---|---|---|---|---|
| Bombay | ...... | 226 | 144 | 43 | 171 | 132 | 35 |
| Lisbon | ...... | 491 | 346 | 176 | 333 | 277 | 153 |
| Greenwich | 1884 | 398 | 269 | 65 | 143 | 112 | 51 |
| St. Petersburg | 1870 | 235 | 142 | 169 | 77 | 53 | 71 |
| Do | 1878 | ........... | ........... | 30 | ........... | ........... | 24 |

I have added the observed results of St. Petersburg for 1878, as they will probably represent better the type of the variation in 1870 than the uncorrected values of that year, which are also given.

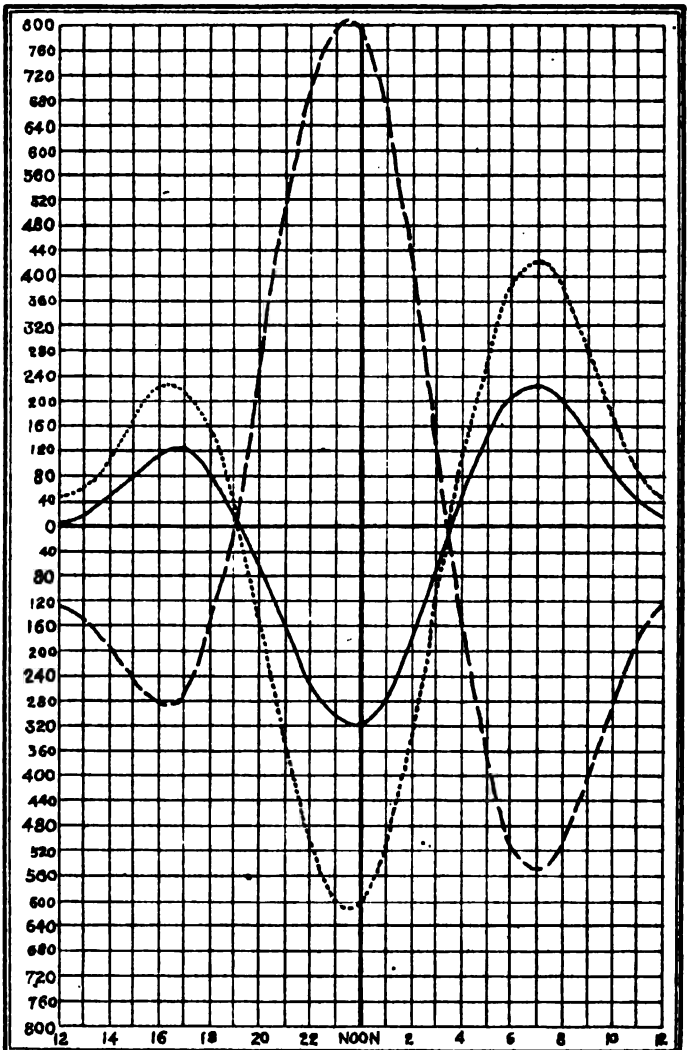
A glance at the tables will show that the phase of the variation is in complete disagreement with what it would have to be if the seat of the variation was inside the earth, and we may take it as absolutely proved by the investigation that the greater part of the variation is due to causes outside the earth. Lisbon and Bombay, and especially the former station, are the two for which our information as regards the vertical force is most complete, and it will be seen that the phase calculated on the assumption that the seat of the disturbance is outside the earth agrees with the record phase to three minutes for the diurnal variation at both places. For the semidiurnal variation the

difference is four minutes at Lisbon and half an hour at Bombay. The results are clearly shown by plotting down the sum of the diurnal and semidiurnal variation, as is done in the accompanying figure. (Plate XIX.)

While the phase of the vertical variations is thus well accounted for, it will be seen from the tables and figure that the amplitude is considerably less than what should be expected. If we then take it as proved that the primary cause of the variation comes to us from outside the earth's surface, we are led to consider that a varying magnetic potential must cause induced currents within the earth, if that body is a sufficiently good conductor. These induced currents might be the cause of the apparent reduction in amplitude. As my colleague, Prof. Lamb, had given considerable attention to the problem of currents in a conducting sphere, I consulted him on this point and he gave me the formula by means of which the induced currents can be calculated. The result of the calculation was remarkable.

Treating the earth as a homogeneous solid, the currents induced in the earth would, if the conductivity was sufficiently great, reduce the amplitude of the observed variation, but at the same time there would be a change of phase which is not shown by observation. If, on the other hand, the conductivity of the earth is not sufficiently great to produce an appreciable change in phase, there could be no reduction in amplitude.

In order to reconcile theory and observation, we are led to the conclusion that the conductivity of the interior layers of the earth is greater than that of the surface layers. It is extremely probable that this is really the case. The bulk of the outside layer of the earth, except in so far as it is water, is made up of material which, in its ordinary condition, is nonconducting, but we know that some of the silicates begin to conduct at temperatures above 200° C., and, generally speaking, insulators lose their insulating powers at high temperatures. Without regard even to the qualities of metallic matter that may be stored inside the earth, there is nothing improbable in the supposition that its conductivity increases toward the inside. If the bulk of the observed induced effect is due to currents in a fairly conducting inner sphere, the calculated phase would be that due to good conducting matter, and would not differ from the observed value, while the reduction in amplitude might yet be sufficient to account for the observed facts. In order to give a better idea of the kind of conductivity which is required to produce a certain change of phase, it may be stated that for distilled water obtained by Kohlrausch, $P$ would be about $1.4 \times 10^{15}$. Such water is, as is well known, a very bad conductor, and, according to our tables, if the whole earth was made up of matter which conducts as badly, there would be no currents in the earth induced by the diurnal variation




LISBON.

Comparison between calculated and observed curve of vertical force. The abscissæ denote astronomical time, the ordinates vertical force, the unit of force being C. G. S. $10^{-6}$.

Observed curve, black line. Curve calculated on hypothesis of outside force, dotted line. Curve calculated on hypothesis of inside force, broken line.

of sufficient intensity to affect our magnetic needle sensibly. Ordinary rain water, however, has a specific resistance of about $6 \times 10^{12}$. A conducting sphere of the same resistance would already produce a retardation in phase of about an hour for the diurnal variation if the solid harmonic is of degree 2. For salt water the resistance may get as low as $4 \times 10^{9}$. A whole sphere made up of such water would very considerably reduce the amplitude of the observed vertical force, and alter the resultant phase by 45°, nearly. The average conductivity of the earth, as seen from these examples, must be small, although it may be considerable over limited areas. Such limited areas would principally affect the harmonic forms of higher degrees, and we should not, consequently, expect for them such a good agreement between theory and observation.

The above discussion of the diurnal variation, although incomplete in many respects, shows the importance of pursuing the subject. The secret of the influence of sunspots on the phenomena of terrestrial magnetism will be brought nearer to solution, and a more complete analysis treating separately of the years of maximum and minimum sunspots. There are several points, however, on which more experimental information is required. It is very much desired that the diurnal variation should be studied in detail over some one definite latitude circle not far away from 45, and, if possible, also on the corresponding latitude circle in the Southern Hemisphere. If we consider that the harmonic analysis of terrestrial magnetism will throw light, as has been shown, on the internal conductivity of the earth, on the external conductivity of space, and on the great problem of solar influence in terrestrial phenomena, it is surely time that a regular and systematic discussion should not be further delayed. An international discussion seems called for, and would probably lead to some subdivision of work and mark an epoch in the progress of our knowledge of cosmical physics.

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## 11.—METHODS AND INSTRUMENTS OF PRECISION FOR THE STUDY OF ATMOSPHERIC ELECTRICITY.

A. B. Chauveau.

### I.—HISTORIC REVIEW.

The celebrated experiment of Dalibard was made on the 10th day of May, 1752. It justified in a clear manner the previsions of Franklin by putting on record for the first time the electric manifestations produced by the clouds.

A few days later Lemounier (*Mémoires de l'Academie des Sciences*, 1752), by securing a better insulation for the metallic wire, of which Dalibard had made use, demonstrated the constant existence of that

which Beccaria some years later called the quiet electricity of fair weather. He indicated the normal sign of it, positive, and at least the suspicion of a regular diurnal variation of the electric state of the air in good weather.

But it is in the remarkable series of observations pursued during fifteen years by Père Beccaria (1757–1772) that he sought the foundation of our actual knowledge of this subject, and the results obtained by this conscientious observer can be consulted to-day with profit.

A little after the same epoch, Cavallo (1777), and still later Saussure, Becquerel, Breschet, Guy-Lussac, and Biot demonstrated that the positive electricity observed in a clear sky, increases with the height.

Finally, it is to Saussure (*Voyages dans les Alpes*, 1786) that the honor reverts of having determined with sufficient precision the elements of the diurnal variation, and thus attaching more strictly the study of atmospheric electricity to that of the other meteorological elements. The results obtained were confirmed by the researches of Schübler (1811 to 1833, *Schweigger's Journal*), since made more precise and extended by the beautiful series of experiments executed at the observatory at Brussels, by Quetelet, during more than five years (April, 1844, to the end of October, 1849).

The observations of Quetelet, superior in regard to precision to all the preceding, were made by the method of Peltier (*Ann. de Phys. et Chimie*, 1842), whose name it would be unjust not to mention here. This physicist in fact first had the exact conception of the electric phenomena, of which the atmosphere is the seat. He proposed for their explanation an hypothesis which is still at the basis of the most generally accepted theories. By the aid of a method analogous in principle, but different in the mode of operation, Dellmann (*Pogg. Ann.*, Vol. LXXXIX, 1853) executed a series of excellent observations, whose results, in the opinion of Sir W. Thomson, may be considered the best which had been published in electric meteorology before the introduction of self-registering apparatus.

## II.—METHOD OF OBSERVATIONS.

1. *Method of the insulated conductor.*—Most of the physicists who before Peltier had occupied themselves in a continuous way with atmospheric electricity employed for their regular observation a vertical insulated conductor with an electrometer. When one raises in the air a metallic wire maintained in insulation, it is electrified by induction, and it is thus put at the potential of the level surface passing through its neutral line. If the position of this line were invariable on the conductor supposed to be fixed in its place, the measures made would give the variation of the electric state at a definite point in the atmosphere. But the insulation of the wire is never

perfect; losses occur not only through the supports, but especially through the surface exposed to the free air. This dissipation, variable with the state of the agitation and the humidity of the air, which is not always the same for different points of apparatus, influences considerably the position of the neutral line. On putting such a conductor in communication with the ground, when the insulation is new, one sees its potential, at first zero, increase slowly in consequence of the losses which take place on its surface, until a certain state of equilibrium is obtained by it. The apparatus is then sensible to electric variations of the atmosphere, although the indications which it furnishes can not be considered comparable for the reason given above.

But the gravest inconvenience which the employment of an insulated conductor presents comes from contact charges which it can receive and retain for a greater or less time, by the rain, snow, mist, and by the masses of electrified air which momentarily surround it. After a fall of rain or snow the indications of the electrometer are false during several hours, if the insulation is sufficient. It is necessary then to bring back the apparatus to zero, and quite a long time can elapse before the state of equilibrium is attained.

If the length of the wire employed is so great that the difference of the potential between the regions near its extremity and the ground is considerable, one can improve the conditions of the experiment by making the wire end in a point, or better by a number of points. The neutral line is thus found to have approached the extremity, and the potential of a point is measured farther from the ground. With a wire sufficiently short, and such that the difference of potential corresponding is not less than some hundreds of volts, the employment of points, however subdivided they may be, is illusory, and adds nothing to the sensitiveness of the instrument. It suffices to convince one of this, by repeating an experiment which is very well known, and which shows that the loss of an electroscope charge in these conditions is not modified, when one provides the instrument with one, or with several very fine points. Whether the conductor be armed with points or not, the inconveniences described above exist, and ought to proscribe absolutely the employment of an insulated wire in a fixed place for the continuous observation of atmospheric electricity.

2. *Method of M. Palmieri.*—But one can obtain the best results by limiting oneself to discontinuous observations, and of sufficiently short duration, so that during each one of them it will be easy to make sure that the apparatus has a sufficient insulation. If one raises a conductor well insulated rapidly into the air, attached to an electrometer in such a way that communication is suddenly interrupted at the moment when the conductor attains a determinate

position, and if one observes the arc of impulse of the needle, the ordinary defects of that method are avoided, and it is perceived that the results obtained, although not precise, can be compared. This is the method invented by M. Palmieri, and employed by him for several years at the Observatory of Vesuvius. It is certainly interesting, but it does not appear to be comparable with the precision which is obtained nowadays in electrical measures. It would be in any case necessary, in order to fix its value, to compare the results with those which are furnished by apparatus that can give with certainty the potential at a point of the atmosphere. No comparison of that kind seems to have been made by M. Palmieri.

3. *Method of Peltier.*—In the employment of an insulated conductor Peltier substituted for the regular observation of the atmospheric electricity a method of which Cavallo and Erman had previously made use, but to which he had given a great simplicity and quite sufficient precision. It consists in principle, following the expression of Sir William Thomson, in raising a portion of the ground which is to be explored to the insulator, in order to make it act afterward upon an electrometer placed in a different position; for example, in a local inclosure. One determines thus its charge, and, if the capacity is known, the difference of potential $V$ between the point explored and the ground is given by — $V = \frac{M}{C}$. We will not describe in detail the well-known apparatus of Peltier; we would recall that it is composed of a very sensitive electrometer, surmounted by a wire about 15 cm. long and a sphere 10 cm. in diameter, the whole instrument having a height of 35 cm. "When I wish to observe the electric tension received in the atmosphere," said Peltier, "I mount upon the terrace where there is established a small tablet raised a meter and a half, upon which is placed the instrument. I bring it to equilibrium by touching the wire in its lowest part; then I descend and replace the instrument in its customary place in the laboratory. All this is done with great rapidity and requires only eight seconds. Being in equilibrium during its elevation, the instrument in lowering itself gives the sign of resinous electricity, while in raising it gives that of the vitrious." Without wishing to insist especially upon an experimental arrangement, now abandoned, we would remark that it has furnished to Quetelet results of great exactness upon the diurnal and annual variations of atmospheric electricity.

Dellmann did better still by the employment of an electrometer of remarkable sensibility, known under the name of Dellmann's Balance, and by happy modifications in Peltier's method of operation. His apparatus, less known than the preceding, consists of a wire surmounted by an insulated metallic sphere, which a system of cord

and pulleys permits to be raised vertically above a roof. After having put the sphere in communication with the ground for an instant, it is brought down and placed in a box, where it remains insulated and free from losses by the air. It is then joined to the needle of the balance, and one observes both the deviation and the torsion necessary to make the needle return to a fixed position. The repulsion being exerted between the needle and a conductor with which it is primarily in contact, there is thus measured a quantity proportional to the square of the charge, —$M = VR$, or to the square of the potential. One can determine in this way the potential of the air in its absolute value. This method is theoretically unexceptionable; it has given, in the hands of skillful experimenters, some excellent results, but the necessity of securing sufficient insulation of the movable sphere during the interval, although very short for an experiment it is true, renders the employment of it too delicate for it to furnish a regular course of meteorological observations. It offers, furthermore, the great inconvenience of not being able to make continuous observations. It is necessary, nevertheless, to retain it for application in particular conditions. M. Pellat has proposed, for the study of the potential of the air at great heights, the employment of small balloons inflated with hydrogen, having a metallized surface, and held by a cord of silk. This process has not yet been employed, but it must be pointed out that its practical realization would not appear exempt from serious difficulties.

4. *Method of Volta.*—It is to Volta (*Lettres sur la Météorologie électrique*, 1787) that we owe the principle of the method almost exclusively employed to-day for relative measures of atmospheric electricity. By placing a lighted match at the extremity of an insulated wire of an electrometer of Saussure, Volta recognized that the indications of the instrument would be considerably increased, although the combustion developed by the same made only a relatively insignificant difference of potential. The gases coming from the combustion are conductors on account of their higher temperature; they are, so to speak, particles of the body which are detached continually from a point of its surface, and reduce that point to the neutral state.

There is thus realized a true equalizer of potential, and that of the body is constantly equal to the potential of the level surface, which passes through the neutral point. The employment of an insulated conductor becomes then suitable; all the uncertainty disappears, and the observation of Volta asserts its claim to be a capital advance in the study of atmospheric electricity.

Volta employed a candle or a stick of sulphur, or even a small lamp placed in an open lantern. Sir W. Thomson has rendered this process more practical by substituting for the flame a current of very

hot gas, obtained by the combustion of a small roll of filter paper impregnated with acetate of lead. But according to Mr. Pellat (*Compt. Rend. de l'Acad. de Science*, Vol. c, 1885) the employment of these matches can occasion considerable errors, resulting from the existence of an electromotive force of combustion, variable during the experiment and oftentimes greater than ten volts. The same physicist has shown that a flame of hydrogen, or of illuminating gas, burning in a night lamp at the extremity of a metallic burner, is put immediately at the exact potential of the air, within half a volt, and appears to be the best conductor which can be employed.

5. *The process of Sir W. Thomson.*—The maintenance of a flame all the time is difficult, and the process of Volta is not easily applicable to continuous observations. Now, on account of the rapid and considerable variations, which the potential of the air at a point experiences, this class of observation is alone suitable for a profound study of the electrical phenomena of the atmosphere. It is to Sir W. Thomson that we owe the method and the apparatus which has permitted it to be realized.

The current of hot gas produced by a flame is replaced by a current of water, which gives to the conductor from which it escapes a potential equal to that of the region where the separation of the liquid drops takes place. For the ordinary electrometers employed Sir W. Thomson substituted an instrument more sensitive, and above all more exact—the quadrant electrometer. Finally, he completed the apparatus by applying to it for the continuous record of the observations the process of photographic registration in use in the meteorological observatories of England. To electric meteorology was thus given an instrument of research of the first order, and the continuous registration of the variations of the potentials of the air was carried out according to the plans of Sir W. Thomson at the Kew Observatory in 1861.

### III.—THE REGISTER OF MASCART.

The most practical form which seems to have hitherto been given to the Thomson register is due to Mascart. We will describe this apparatus in detail, and discuss in this connection the conditions which the installation ought to satisfy, so that all cause of error should be avoided in the results.

1. *The register.*—The register properly called is composed of a gravity clock, connected by a rack to a vertical frame which descends its whole length in twenty-four hours. Upon this frame there is placed, between two planes of glass, a sheet of photographic paper. The source of light is a vertical slit illuminated by a small oil lamp; this lantern is fixed at one side, on the case of the clock. The light falls on the mirror of the electrometer after traversing a plano-convex

lens fixed upon the case of the instrument, resulting in two images; the one small and fixed, proceeding from a partial reflection upon the posterior plane face of the lens; the other, more brilliant and movable, is given by the mirror. They are received upon a horizontal practically straight slit in the wall, behind which is placed the sensitive paper. The fixed image draws a straight line. From this axis the ordinates of the curve traced by the movable mirror can be measured. The electrometer is, furthermore, so regulated that the two images are superposed when the needle is in communication with the ground. To mark the hours it is sufficient to trace upon the plate of glass in front of the frame a series of very fine and opaque horizontal lines, which interrupt the curve at equal intervals.

With regard to convenience, certainty of movement, and even elegance, this instrument leaves nothing to be desired, but for occasional observations, or in certain particular conditions which do not permit the employment of a gravity clock, a simpler instrument can be substituted for it. The register employed for the observations of atmospheric electricity, made at the summit of the Eiffel Tower, is a Richard cylinder, mounted horizontally and turning in the interior of a metallic envelope, in which a straight slit is pierced along a generatrix. The photographic paper is wrapped around the cylinder, the sensitive face applied against the metal, so that it is the back of the sheet which is presented to the luminous impression. Perfectly fine curves are obtained on traversing the thickness of the paper in the same conditions as before, that is to say, with a small oil lamp. One thus avoids contact of the fingers upon the sensitized face, which is inevitable in unrolling, at the same time rendering easier the process of placing the sheet upon the cylinder.

*Electrometer.*—The electrometer employed by Mascart is a modification, now well known, of the quadrant electrometer of Thomson. The two pairs of sectors connected to the poles of a battery, of which the middle is grounded, have the potentials equal and of contrary signs. The needle, suspended by a bifilar of cocoon thread, is traversed along its axis of rotation by a platinum wire, which plunges in a glass dish filled with sulphuric acid. It is put thus in communication with the collector by the intervention of this liquid, which has, furthermore, the effect of securing insulation by maintaining the air dry in the case. This instrument, well regulated, is perfectly symmetrical and, within the limits of the few degrees which the field of the register permits, its indications are proportional to the potentials of the needle.

Mascart's electrometer has been frequently blamed for the ease with which the zero is displaced in continuous observations, if one is not careful to renew the sulphuric acid frequently. (*Conférence International pour les détermination des unites électriques, 2ieme session,* 1884.)

M. Ròiti has even thought that he ought for this reason to avoid the employment of a bifilar with cocoon thread. This inconvenience, in fact, exists with a new thread, especially if this has not been suitably untwisted before being put in place. During the first months of the working of the apparatus installed in the Central Meteorological Bureau it was necessary to renew the acid every five or six days, in order to secure a sufficiently stable zero. Now the same thread is always in use and the zero is never displaced. The acid is renewed generally every month and often at longer intervals. One avoids, furthermore, all displacement of the zero, even with a new thread, by giving a sufficient deviation to the support of the bifilar and by increasing, in consequence, the number of elements of the battery. It is always preferable to place it in these conditions. The stability of the needle is greater and the trace of the photographic curve is finer.

The battery ordinarily employed to charge the sectors is a water battery of Volta, formed of small porcelain dishes resting on a bed of sulphur and immersed in paraffin. Whatever precautions may be taken, this battery polarizes itself very rapidly, and its employment should not be recommended. It attains, it is true, after awhile, a sort of condition that is more or less permanent, for which the difference of potential between its poles is less than half the primitive difference. The sensitiveness of the electrometer is at the same time almost constant, but it will be found to be somewhat modified every time that water is added to the dishes to replace the loss due to evaporation. It would be preferable to have recourse either to the Daniel or to the Gouy elements. These last are especially easy of installation; the volume can be reduced at will, and their constancy is remarkable. In every case it should be assured that the sensitiveness of the electrometer has not varied and it is convenient to make at least once a week a graduation, by putting the needle successively during some minutes in communication with each of the poles of a standard battery, the other pole of which is connected to the ground. There is found upon the sheet of photographic paper the trace of the deviations obtained.

3. *Collector.*—The collector is a metallic vessel of about 60 liters capacity, insulated upon three glass supports kept in an atmosphere dried by sulphuric acid. It is placed near a window, and the drain-pipe projects horizontally outside about one and a half or two meters from the wall. The employment of insulators in sulphuric acid, conceived by Sir W. Thomson, gives the best results; it is proper to have it renewed as often as circumstances permit. They are, furthermore, very convenient to use, for it ordinarily suffices to remove the acid every three or four months, after having washed in much water and then dried carefully the dishes.

One can thus employ, with success, paraffin to secure a durable

insulation for the apparatus exposed to the free air, and frequently surrounded by mists. The water-collector placed on the summit of the Eiffel Tower is in this form; it is insulated upon three glass tubes sealed in a layer of sulphur at the bottom of a flat box, which is entirely filled by washing with paraffin. The insulation thus obtained is equivalent to that which the best supports in sulphuric acid would give, but under this absolute condition that the surface of the paraffin remains clean from all dust. Very easily realized at the height of 300 meters where the air contains only very little solid matter in suspension, this condition is a serious obstacle to the employment of paraffin for continuous observations near the ground.

The drain tube terminates in a straight orifice, such that the mean loss is about two liters per hour. With a sufficient insulation the needle, originally put at zero, takes about one minute to attain its position of equilibrium. One should perhaps indicate a longer time for the duration of the charge by dropping of water; this time evidently varies with the loss, the electric capacity, and the state of insulation of the apparatus. In the normal conditions, and for a metallic receiver well insulated, the indicated loss of two liters per hour is entirely sufficient, so that the indications of the needle could have no appreciable retardation, at least on the photographic trace.

We have said that the drop collector takes a potential equal to that of the layer of air, which is near the point where the separation of the liquid drops is made. It is consequently essential to secure for this point a fixed position. Now this condition is by no means realized in the common arrangement. The point of separation of the liquid drops changes, first through the effect of the pressure, which diminishes in proportion as the level of the liquid lowers in the receiver, then by the effect of the wind which modifies at every instant the form and direction of the jet. The corresponding variations of the potential observed are far from being insignificant; they correspond for a dropping tube of two meters to one-tenth of the quantity to be measured, and their importance increases with a shorter tube. The results obtained under these conditions are in truth comparable to those which a thermometer would give for temperature, simply exposed to the north along a wall and without shelter.

Such is, it seems to us, the capital defect in the ordinary process of observation. One can easily remedy it by taking for collector a large and shallow vessel (70 centimeters in diameter by 15 centimeters in height) prolonged below by a straight cylinder, of which the height will preserve almost constant the pressure under which the dropping is made. The horizontal tube attached to the lower part of this cylinder and held by a rest fixed to the body of the basin will terminate by a spout in a ball of a watering pot, pierced by very many straight

holes. The diameter of these orifices ought to be such that under the pressure, measured by the height of the vertical cylinder, the dropping should be made by jets very fine and of short length. A sieve of light linen cloth, mounted upon a metallic frame, and fixed by a movable arm to the opening of the cylinder in the basin, stops the obstruction of the holes of the spout. This arrangement permits, furthermore, the reduction of the loss. In fact, as M. Pellat has remarked, the liquid drops are smaller, but their volume being proportional to the cube of the radius, while the electric capacity is in direct ratio to the first power, the quantity of electricity carried away is greater for the same volume run out.

### IV.—ABSTRACT OF THE OBSERVATIONS.

It is known that the curves of potential furnished by the self-registering apparatus have a very different aspect from those which belong to other meteorological elements; the trace is extremely irregular. In an interval of some minutes often during the day, the variations are equal to three or four times their mean value, and they can be much greater still. The discussion of such curves is difficult and leaves room for many uncertainties. It can be said without much exaggeration that in ordinary conditions it would be necessary to read the observations every ten minutes in order to have a sufficiently approximate value of the mean potential of the day. On the other hand the trace of a mean curve, to which they sometimes resort, is delicate, and does not offer the guarantee that the results obtained by different observers can be considered really comparable. If it is proper to leave to the apparatus of research, properly so called, all the sensitiveness of which they are capable, one ought to take care for the regular observations, such as are carried on in an observatory, to diminish upon the curves obtained, without altering the mean value, the amplitude of these accidental variations, which their too short duration does not permit to be attributed to any accompanying meteorological phenomena, and which are moreover an obstacle to the proper interpretation of these results. One can accomplish this by interposing between the collector and the electrometer a convenient and carefully insulated capacity. The variations of the potential are, so to speak, totalized during a variable time, according to the additional capacity, and the electrometer gives the mean corresponding state.

The employment of a very small condenser made of a glass tube, filled partially with mercury and covered with tin on the lower part, and insulated in the interior of a dish containing sulphuric acid, deadens, so to speak, the oscillations of short duration and, without modifying in any respect the design of the curve, substitutes for the ordinary small teeth a very fine trace upon which the readings are easily made.

### V.—MEASURES OF HIGH POTENTIAL.

The sensitiveness of the electrometer ought to be regulated in such a way that the field of the register corresponds to the variations observable in the normal system. To fix the ideas of this subject we will say that in the ordinary fields of observation, such as are practiced, for example, at the Central Meteorological Bureau, at Paris, with a drain tube, emerging two meters from the window of the second story, and overtopped by the roof at a height of three or four meters, the diurnal mean potential at the time of the minimum of summer is about 150 volts; at the maximum of winter it is 700 volts. The absolute maximum in good weather can attain 500 volts in the first case and 1,200 volts in the second.

But in times of rain or snow, in certain fogs, and during thunderstorms, there are produced differences of potential much greater, both positive and negative, which throw outside the field of register the luminous image of the electrometer. It does not appear that sufficient attention has been given heretofore to evaluate the intensity of these phenomena often enough, because it is difficult to neglect them in a complete study of the electric manifestations of the atmosphere. The simultaneous employment of two electrometers of very different sensitiveness, registering their indications on the same sheet, is easy to realize and seems to be able to fill this gap. The potentials to be measured are frequently more than 4,000 volts. On the other hand the measuring instruments ought to be as symmetrical as possible; in every case it ought to give, not only the magnitude, but also the sign of the phenomena observed. Now, the quadrant electrometer, at least in its ordinary form, does not appear to lend itself to the measure of high potentials. Above a certain limit the sensitiveness decreases very rapidly with the charge, in such a way that between 2,500 and 3,500 volts the deviation of the needle remains sensibly constant. Practically, it can be said that the deviation has a limiting value, variable according to the coefficient of torsion of the bifilar, and which corresponds to a potential of about 3,000 volts.

Such is the condition which we have very nicely arranged for a Mascart electrometer, perfectly insulated and modified so as to permit the needle to sustain without rapid loss much higher potentials than 3,000 volts. It has been pointed out heretofore for instruments of an entirely different model, at first by Mr. Hopkinson (Proceedings of the Physical Society, Vol. VII, p. 1), then by Ayrton, Perry, and Sumpner (Trans. Roy. Soc., Lond., vol. 182, 1891, pp. 519–564), who have made a minute study of the experimental conditions of this singular phenomenon. In default of an instrument which does not appear to have been yet realized under a form appropriate for observations of atmospheric electricity, one can, by a very simple device, utilize the

quadrant electrometer for the measure of very high potentials, all remaining in the ordinary limits of the sensitiveness of this apparatus. It suffices for this to place between the source and the electrometer a cascade of three small condensers, well insulated. By varying the number of the condensers there can be thus given to the needle such a fraction of the primitive potential as is desired. It is this process that we have used for the registration of atmospheric electricity at the top of the Eiffel Tower. The dropping apparatus, placed above the third platform at the height of 287 meters, gives for the mean diurnal potential, taken at one meter and a half from the railing of the tower, about 5,000 volts at the minimum of the summer (it is then about 150 volts near the ground), and the maximum of the day in good weather frequently surpasses 10,000 volts. It is sufficient to cite these figures to make it understood that such determinations do not possess the precision of the laboratory measures. It remains to be said that for such high potentials the continuous insulation of an apparatus partly exposed to the free air presents considerable difficulty. We hope to have sufficiently secured it, so that, except in days of rain or of exceptional humidity, the accuracy of the results obtained will not be inferior to the approximation which the lines upon the photographic trace permit.

### VI.—PORTABLE APPARATUS.

The rapid variations of the potential of the air at a point transfers a great part of their value to discontinuous observations made singly. It is at least necessary, if one wishes to have available data, to prolong each experiment during a time sufficiently long to be able to deduce a mean value. But the observations of this nature are necessary, and assume a great importance if the influence of the conditions of the installation of the apparatus is going to be determined by the comparison of results obtained simultaneously.

Among the instruments employed for these rapid determinations the most accurate, and probably, also, the most convenient, is Thomson's portable electrometer. This apparatus is now too well known to be described here. Let us recall simply that it is composed of an ordinary gauge of the absolute electrometer, placed in a glass vessel communicating with a tin covering, which lines the bottom of the vessel on the interior. The outside surface of this bottom is equally covered with tin. An attractive plate, parallel to the gauge, can be united to the ground or to the collector. It is moved by a micrometric screw, by means of which it is raised or lowered until the gauge is brought back between its marks. The air of the glass is dried by sulphuric pumice stone. The practical qualities of this electrometer depend before all upon its accuracy of construction, and

principally upon the nature of the glass which forms the envelope; that ought to be perfectly insulated. It is necessary, in fact, that the observer should not be under the necessity of making for each experiment the falling off of the instrument, and this supposes an extremely slow loss for the charge of the gauge. The loss may be less than one-half to one-hundredth in twenty-four hours in a well-constructed apparatus.

For observation one takes the electrometer in the hand, surmounted by a thin stem, at the extremity of which there burns a match of filter paper, impregnated with the acetate of lead. We have said before that it is proper to make some reservations concerning the employment of this result. In a beautiful series of researches made in the regions of the Alps and Italy, and followed later by a voyage around the world, Exner (*Repertorium der Physik, Münch.*, XXIII, 1887, pp. 656–669) made use of a very simple electrometer, quite portable, which is only a modification of the gold-leaf electroscope. He employed as insulator ebonite, and used for collector the flame of a candle or a small lamp placed in a lantern.

If it is demanded of the electrometer that it indicate the magnitude and not the sign of the phenomenon observed, one can imagine a great number of portable instruments which are sufficiently precise. But a difficulty exists, of which it is necessary to take account, in all researches relative to atmospheric electricity, namely, to secure to the apparatus a proper insulation. Upon this point of detail, as well as upon the question of method, it does not appear that one can do better than to follow the directions of Sir W. Thomson.

Thanks to the illustrious English physicist, for more than thirty years, electric meteorology possesses an irreproachable process of observation and excellent instruments of measurement. It seems that this branch of science, which interested so deeply the physicists of the last century, ought before long to enter into a fruitful path and make rapid progress, and it is a pity if we do not surpass the results which we owe to the patient researches of Quetelet and Dellmann. It is a paradoxical saying which comes involuntarily to mind: "Nowadays we register much, but observe little."

DESCRIPTIVE NOTES ON THE CONSTANTS AND THE WEATHER, ACCOMPANYING THE CURVES OF ATMOSPHERIC ELECTRICITY SHOWN ON PLATES XX–XXV.

B. C. M. = *Central Meteorological Bureau.* E. T. = *Eiffel Tower.*

June 1 and 2, 1893.—

B. C. M., 1 mm. = 5 volts. E. T., 1 mm. = 95 volts; Is. = 75 mm.; Is. = 70 mm.

Sky generally cloudy, with moderate wind from the north during the day. Calm and quite clear during the night. Sky a little cloudy, with moderate wind from east-northeast on the morning of June 2.

Remarks: Very great analogy between E. T. and B. C. M. for the day, June 1; discordance for the evening and night; complete opposition for the morning of June 2.

June 2 and 3, 1893.—

B. C. M., 1 mm. = 5 volts. E. T., 1 mm. = 95 volts; Is. = 70 mm.; Is. = 85 mm.

Sky generally cloudy, with moderate wind from the east-northeast during the day. Sky covered with clouds of a stormy aspect from 7 to 9 p. m. Calm but not very clear during the night. Sky milky, with wind moderate from the north on the morning of June 3; temperature became normal.

June 3 and 4, 1893.—

B. C. M., 1 mm. = 5 volts. E. T., 1 mm. = 95 volts; Is. = 85 mm.

Sky generally cloudy, with moderate wind from the north during the day. Sky very clear during the night. Sky milky, and 9.9 light cirro-stratus (nebulous 0 — 1), with light wind from the northwest the morning of June 4.

Remark: B. C. M. and E. T. analogous.

June 15 and 16, 1893.—

B. C. M., 1 mm. = 7 volts. E. T., 1 mm. = 100 volts; Is. = 60 mm.

Sky generally covered and overcast, with wind from the north; almost calm during the day. Sky alternately almost clear and almost covered during the night. Sky cloudy and milky, with light wind from northwest the morning of June 16.

June 16 and 17, 1893.—

B. C. M., 1 mm. = 7 volts. E. T., 1mm. = 100 volts; Is. = 60 mm.; Is. = 115 mm.

Sky a little cloudy, with moderate wind from the northwest during the day. Very beautiful, clear sky during the night. Calm and quite clear, with moderate wind from the northeast the morning of June 17. Quite a beautiful day.

June 18 and 19, 1893.—

B. C. M., 1 mm. = 7 volts. E. T., 1 mm. = 100 volts; Is. = 115 mm.; Is. = 115 mm.

Very beautiful sky, with 9.9 light clouds (nebulous 0), and moderate wind from northwest. Very beautiful, clear sky, with light wind from the northeast during the night; 9.9 alto-cumulus (nebulous 0) between 8 and 9.30. Sky slightly misty, with very light wind from the southwest on the morning of June 19. Very fine day; maximum temperature, 32.0°.

June 19 and 20, 1893.—

B. C. M., 1 mm. = 7 volts. E. T., 1 mm. = 100 volts; Is. = 115 mm.; Is. = 115 mm.

Sky generally a little cloudy, with light wind from west during the day. Sky covered during the night; sprinkle at St. Maur. Sky covered or very cloudy, with very light wind from southwest the morning of June 20; sprinkle 7 a. m.; maximum temperature, 32.0°.

June 21 and 22, 1893.—

B. C. M., 1 mm. = 7 volts. E. T., 1 mm. = 100 volts; Is. = 85 mm.; Is. = 105 mm.

Sky generally a little cloudy, with light wind from northeast during the day. Sky calm and of ordinary clearness during the first part of the night. Sky calm and very slightly milky at the horizon, with light east-southeasterly wind the morning of June 22. Quite a beautiful day.

July 4 and 5, 1893.—

B. C. M., 1 mm. = 9 volts. E. T., 1 mm. = 90 volts; Is. = 95 mm.

Sky generally a little cloudy near 3 p. m., but the sky clouded up at evening; thunderstorm and rain from 5.30 to 5.50 p. m., 6 to 6.20 p. m., and 7 to 7.10 p. m. Sky cleared at 9.30 p. m., and remained calm, becoming more clear during the night; much lightning in the north from 7 to 11 p. m. Rain till about 10.20, with light wind from southwest the morning of July 5; thunder at 8.45; maximum temperature, 33.5°.

Batteries recharged, and the electrometer readjusted on July 4.

July 10 and 11, 1893.—

B. C. M., 1 mm. = 9 volts. E. T., 1 mm. = 90 volts; Is. = 100 mm.

Sky generally very cloudy, with light wind from southwest during the day. Sky generally covered during the night; sprinkle at 11 p. m., and rain during the night. Sky very cloudy, with light or moderate wind from southwest the morning of July 11.

July 13 and 14, 1893.—

B. C. M., 1 mm. = 9 volts. E. T., 1 mm. = 90 volts.

Sky generally very cloudy and rainy, with moderate wind from southwest during the day; thunder from 11.25 to 11.35 a. m., and from 3 to 5.35 p. m.; distant lightning at 11.55 a. m.; rainbow in the sky at 7 p. m. Sky generally covered during the night. Sky covered and rainy, with light wind from between northwest and north-northeast the morning of July 14.

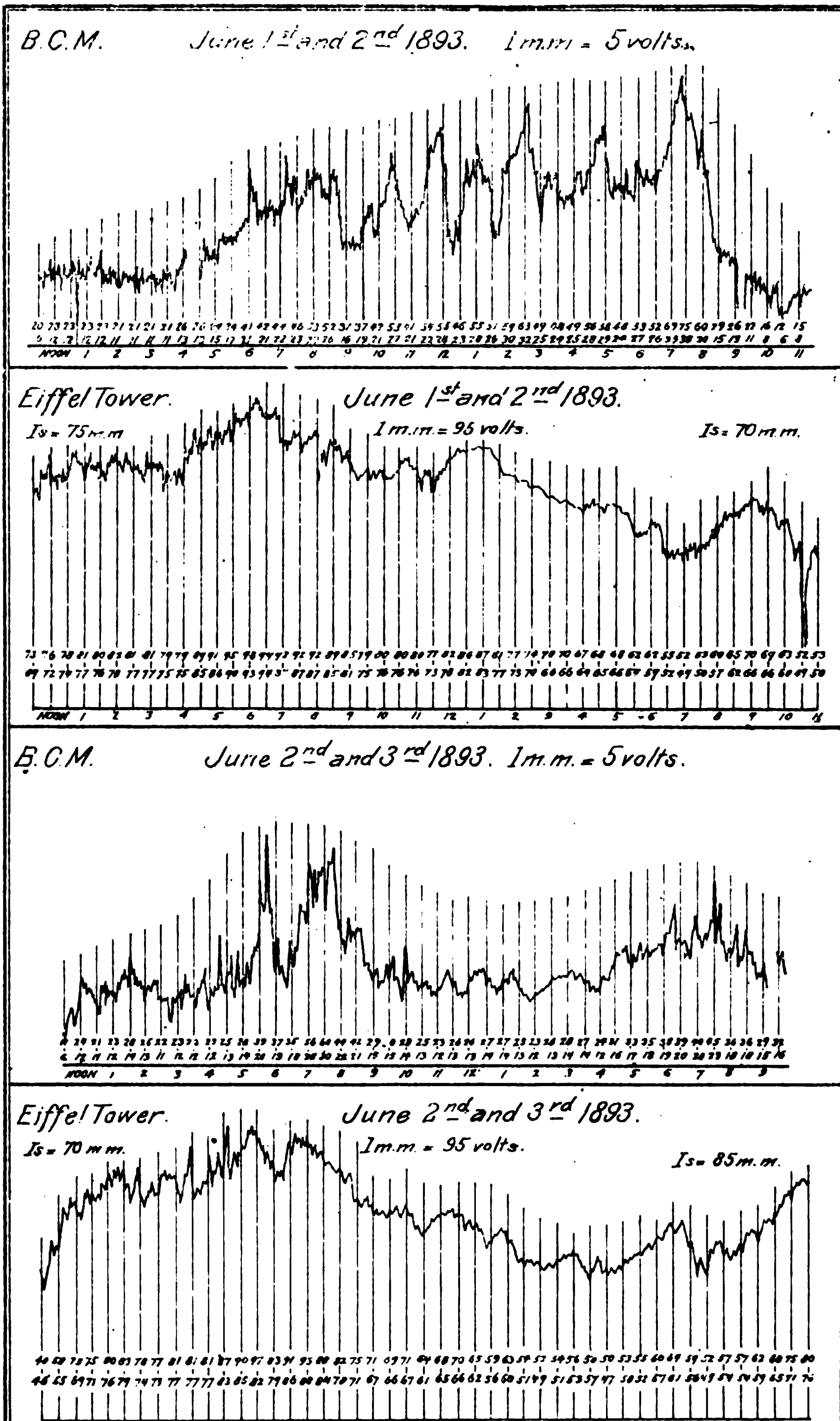
July 15 and 16, 1893.—

B. C. M., 1 mm. = 9 volts. E. T., 1 mm. = 90 votls.

Sky generally covered or very cloudy, with light winds from northwest during the day; light fine rain from 1.55 to 2.30 p. m. Sky generally very cloudy during the night. Sky covered, with quite a strong wind from south the morning of July 16; sprinkle from 10.15 to 10.35.

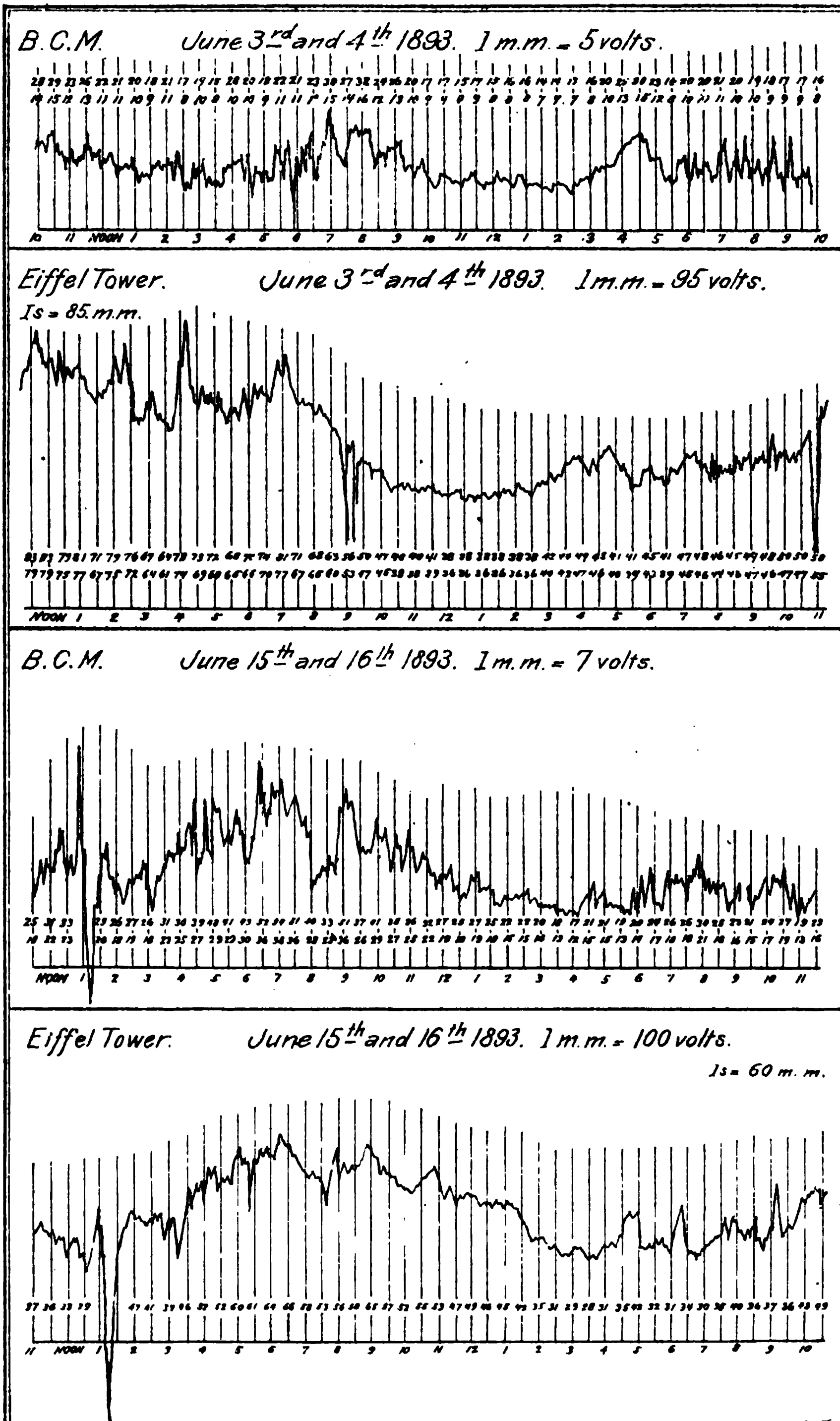
END OF PART II.

Plate XX. ELECTROMETER CURVES. *Chauveau.*



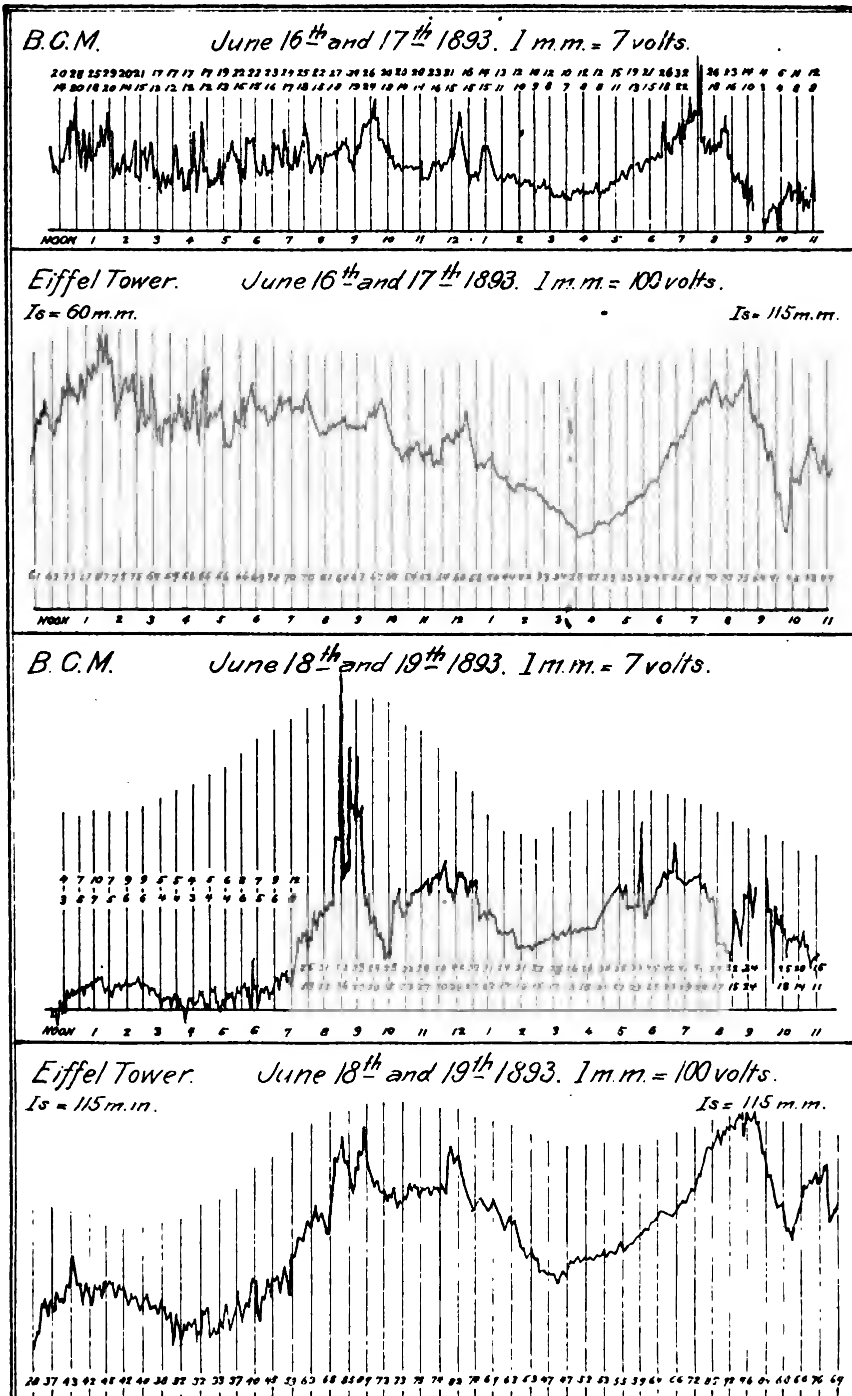
# ELECTROMETER CURVES.

**Plate XXI.** *Chauveau.*



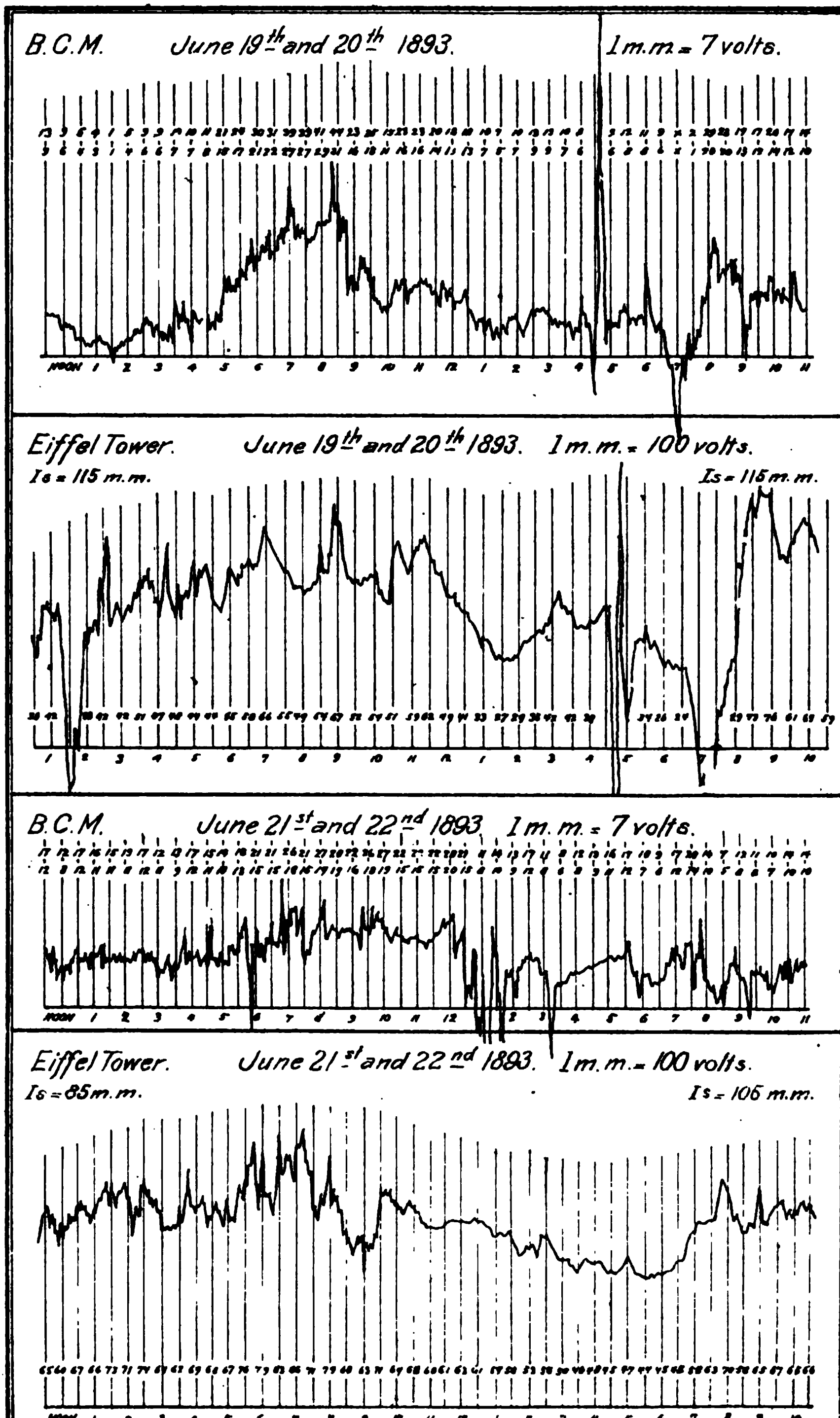
## ELECTROMETER CURVES.

**Plate XXII.** *Chauveau.*



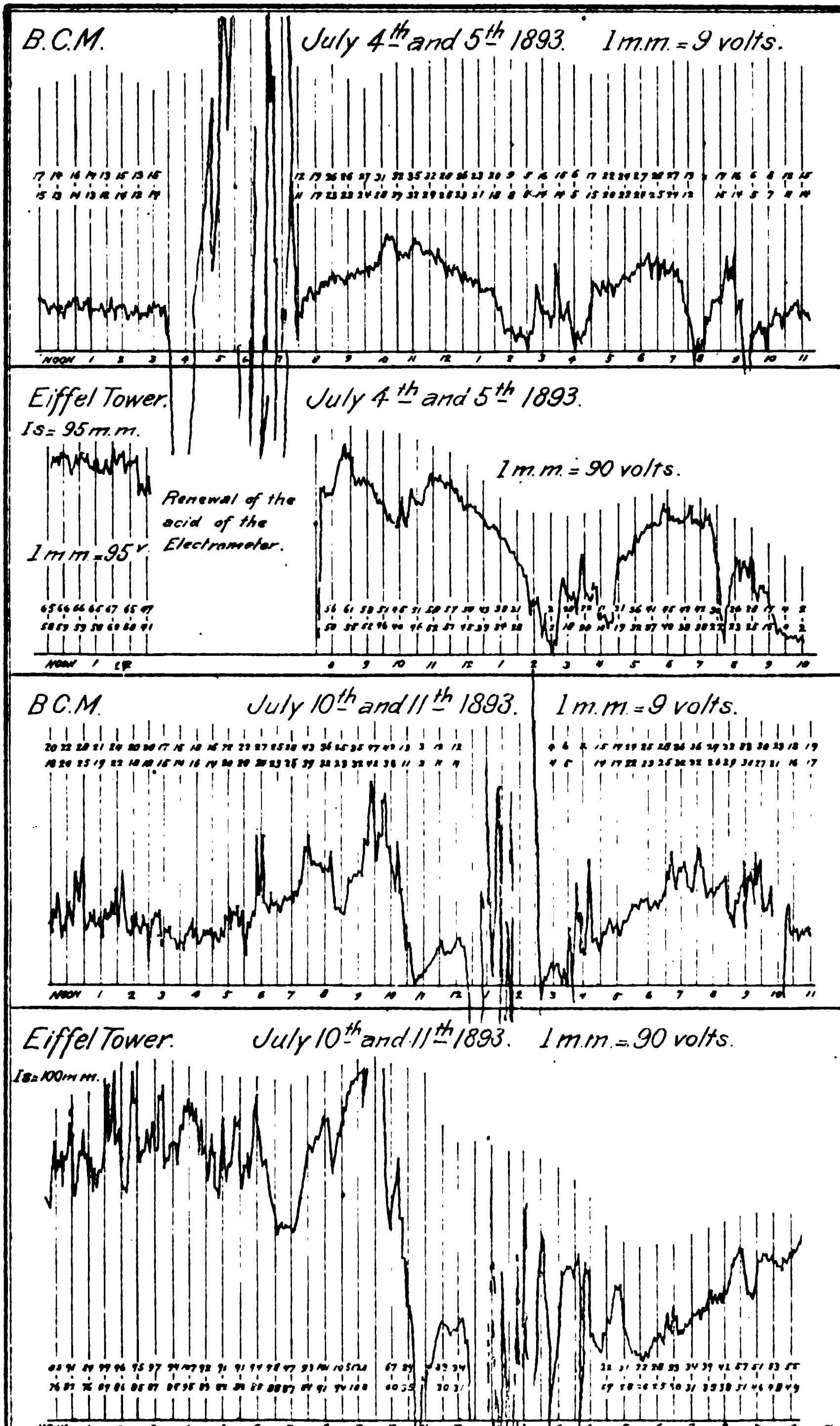
## ELECTROMETER CURVES.

**Plate XXIII.** *Chauveau.*



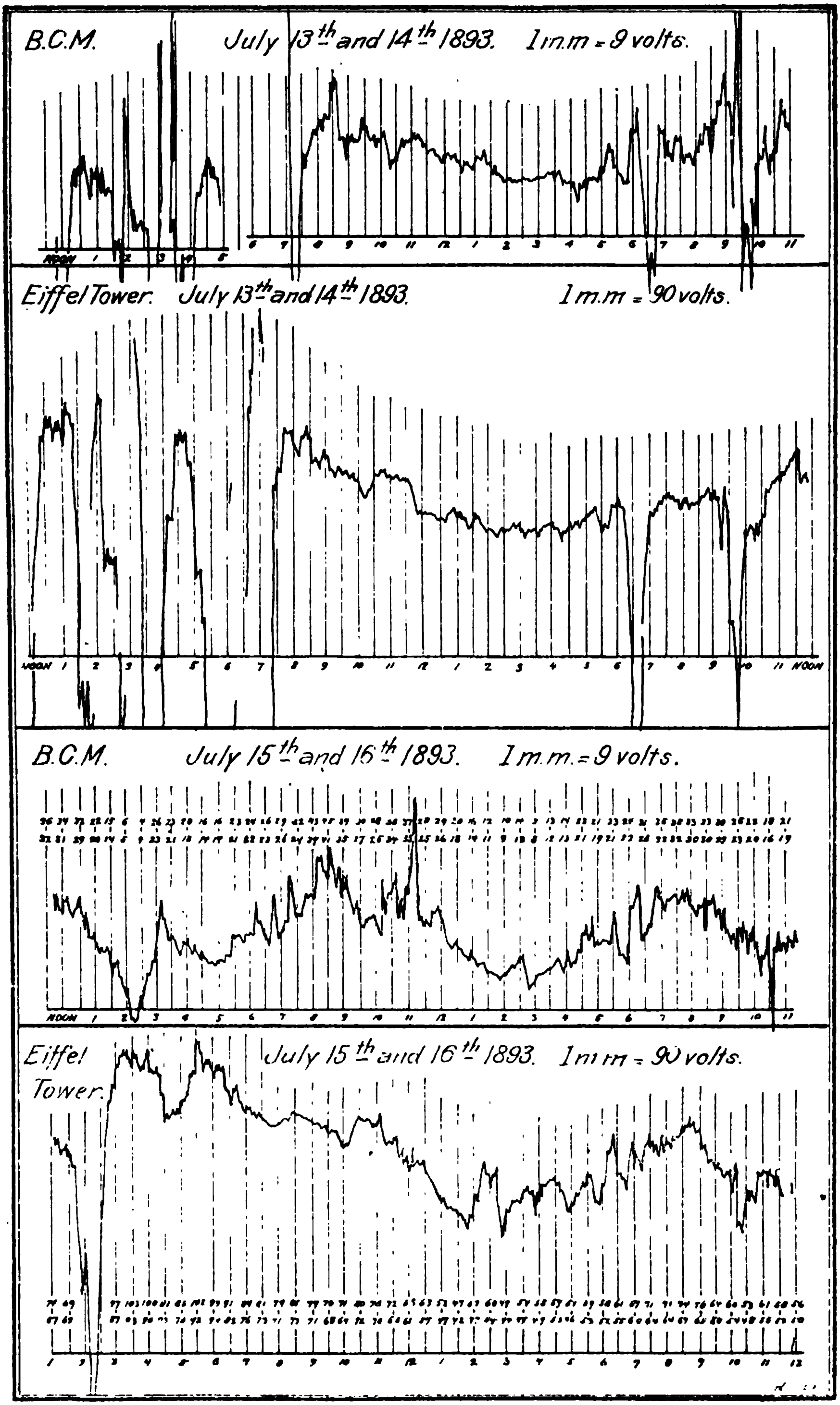
# ELECTROMETER CURVES.

**Plate XXIV.** *Chauveau*



## ELECTROMETER CURVES.

**Plate XXV.** *Chauveau.*



**Bulletin No. 11—Part III.**

U. S. DEPARTMENT OF AGRICULTURE,

WEATHER BUREAU.

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# REPORT

OF THE

# INTERNATIONAL METEOROLOGICAL CONGRESS,

HELD AT

CHICAGO, ILL., AUGUST 21-24, 1893,

UNDER THE AUSPICES OF THE

**Congress Auxiliary of the World's Columbian Exposition.**

## PART III.

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EDITED BY

OLIVER L. FASSIG,

SECRETARY.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

1896.

# PAPERS READ

BEFORE THE

# CHICAGO METEOROLOGICAL CONGRESS.

AUGUST 21-24, 1893.

## PART III.

NOTE.—In the absence of Mr. Fassig all the translations offered by various colaborers have been revised and the proof sheets read by Prof. Cleveland Abbe.

# TABLE OF CONTENTS.

## PART III.

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# ERRATA.

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## BULLETIN NO. 11, PART I.

Page 13, line 11 from top, in place of "W. L. Dallas" read "J. Eliot."

Page 432, line 7 from bottom, in place of "I" read "J."

NOTE.—Two important MSS. prepared with great care for the Meteorological Congress by Dr. Neumayer, Director of the German Marine Observatory, Hamburg, were lost in transmission by mail. Unfortunately no copies were retained by Dr. Neumayer, so the papers could not be included in this report. They were entitled:

(a) International Cooperation in Prosecuting Work and Publishing Results in Ocean Meteorology.

(b) On the Cartographic Presentation of the Distribution of the Forces of Terrestrial Magnetism and their Variations.—EDITOR.

## BULLETIN NO. 11, PART II.

Page 511, line 3, for "fully realize the difficulty and complexity of it," read "lack sagacity and assiduity."

Page 511, lines 13, 14, for "each brilliant discovery," read "that brilliant inauguration."

Page 511, line 28, for "methods," read "hypothesis."

Page 513, line 18, for "precipitation," read "observation."

Page 515, line 15, for "electrified masses of the earth are carried through the discharge into the air," read "electrified masses dispersed into the air are carried back again to the earth."

Page 515, line 9 from bottom, for "electrification," read "discharge."

Page 516, line 3, for "diminution," read "increase."

Page 516, lines 24, 25, "for diminution," read "variability."

Page 517, line 6 from bottom, for "insulation," read "insolation."

Page 518, line 2, for "brought to reach," read "brought to an end on reaching."

Page 518, line 3, for "insulation," read "insolation."

Page 518, line 22, for "periodicity," read "aperiodicity."

Page 519, line 13, for "This impression is produced," read "But doubt is excited."

Page 519, line 8 from bottom, for "Sprung," read "Spring."

Page 520, line 5, for "show," read "overlook."

Page 520, lines 6, 7, for "by no means an insulator or separator of electricity in the ordinary sense," read "an insulator and a separation of electricity in the supposed sense is impossible."

Page 520, line 18, for "charges," read "discharges."

Page 520, line 6 from bottom, for "charge," read "flash."

Page 521, line 7, for "Obermayr," read "von Obermayer."

Page 521, line 9, for "mode," read "kind."

Page 521, line 8 from bottom, for "to be insufficient," read "to show that there is a close connection."

Page 521, line 7 from bottom, for "in these places," read "at this point."

Page 521, line 6 from bottom, for "acted in the path," read "which may explain the circulation."

# PART III.

## PLATES.



## FIGURE.

## SECTION VII.

# CLIMATOLOGY.

### 1.—THE CLIMATE OF THE UNITED STATES.

Prof. H. A. HAZEN.

The climate of a region is its condition as regards air temperature, rainfall, winds, etc., especially in their relation to human, animal, or plant life. The United States, exclusive of Alaska, extending from latitude 25° to 49° N., displays nearly all the variations of climate known in the temperate zone. As is well known, the sun, the frequency as well as the intensity and direction of low and high areas of pressure, the average air pressure, and the direction and velocity of the wind are the principal factors concerned in forming climate. Minor factors are the topography, the presence of bodies of water, thunderstorms, and the condition of the atmosphere up to great heights. One of the most interesting facts that may be mentioned in this connection is the low winter temperature of this country as compared with that of the same latitudes in western Europe; for example, the temperature of 32° F. at New York, latitude 40° 43′, is met at Hamburg, Germany, 950 miles farther north. This difference is due, in part at least, to the higher temperature in the upper air in Europe. Glaisher found in his ascensions in England a fall in temperature of 1 degree in 1,000 feet after he reached 10,000 feet, but at Pikes Peak, Colorado (14,134 feet), the diminution is 1 degree in 300 feet. The winter temperature of Sonnblick, in Austria, 4,000 feet higher and 200 miles farther north than Mount Washington, New Hampshire, is the same as that of the latter.

*High areas and storms.*—The permanent low-pressure area in the North Pacific contributes many of the storms that appear in the extreme Northwest. These depressions sometimes reach 29 inches, but, strange to say, they are what may be called dry storms, as they do not gain moisture enough for precipitation in the east and southeast quadrant till they reach the lake region. Another singular fact is that these storms may have a considerable precipitation on the west and northwest side when these parts are in the region to the west of the middle and upper Mississippi valleys. Other storms come up from the Gulf of Mexico and pass over the lakes; these give the most abundant precipitation to the country east of the Mississippi. The lower lake region

and the St. Lawrence Valley form the great highway for nearly all the storms of the country (80 to 85 per cent).

In the months of August to October there are peculiar depressions called hurricanes, which are formed in the Caribbean Sea toward the east, and, moving first in a westerly direction, recurve in Florida or the eastern Gulf of Mexico and move up the Atlantic Coast, gradually enlarging and at the same time diminishing in energy. These are most violent at times and dangerous to the coast cities and to shipping.

*Average air pressure.*—In the cold months, November to March, the normal charts show areas of high pressure in the South Atlantic States and in the region to the north or west of the middle Rocky Mountains. The latter high area moves east occasionally to the middle and upper Mississippi valleys, and when this is the case the whole country east of the Mississippi is visited by cold weather and temperatures far below the normal.

In the remaining months the Rocky Mountain high area moves to the Pacific and its place is taken by a low area. The second high area moves to the Middle Atlantic and sometimes it takes a position to the west of its normal place, in which case the eastern part of the country is brought under most intense heat. Such was notably the case in May, 1881. All the year through there is a permanent low pressure at the mouth of the St. Lawrence, due, in part, to the passage of storms as just suggested, and, in part, to the permanent low-pressure area over Iceland or the North Atlantic.

*Winds.*[1]—The distribution of the winds is in accordance with that of pressure just given—that is, out of high areas, and around them clockwise, and into low areas, and around them counter-clockwise. For example, from March to October the winds are emphatically from the high area in the Pacific, and this explains in part, if not entirely, the lack of rain during these months, for the cool, damp wind of the ocean has its relative humidity diminished by the heat of the land. The general direction of the wind east of the Rockies, and north of 30° N., is from the west, with the exception that in the lower Mississippi Valley and in Texas they are quite constant from the south.

Distinctive trade winds are found south of 25° only and these are modified by the permanent high area in the South Atlantic. It may be said that the upper current is constant from the west over the whole country all the months of the year, excepting a slight tendency in the warmer months for the upper current to coincide with the lower in the trade-wind region.

The wind on Pikes Peak, latitude 38° 50′ (14,134 feet), averages N. 82° W. a very little south of that in the warm months and north in the opposite season. On Mount Washington, latitude 44° 16′ (6,300 feet), near the Atlantic, the wind is from N. 57° W., steady all the months, N. 48° W. in April and N. 62 W. in June being the extremes.

[1] In all that follows Alaska is excluded.

*Temperature.*—The lowest mean January temperature is −5° in the northern portions of North Dakota and Minnesota. This makes a gradient of 1° F. per 25 miles from the Gulf to the extreme northern border, the former temperature being 55° F. On the Pacific Coast the temperatures are 37° to 53° from the north to the south, a gradient of 1° F. in 70 miles. On the Atlantic Coast the range is from 20° to 65°, a gradient of 1° F. in 30 miles. The highest mean January temperature is 71° F. at Key West. In July the lowest temperature, 56°, is found at Eureka and Tatoosh islands, on the Pacific Coast. A temperature of 68° at San Diego, Cal., rises to 92° F. at Yuma (the highest in the country at any regular station). The range in the central region is from 66° to 84°, or a gradient of 1° F. in 85 miles. On the Atlantic Coast the range is from 60° to 82°, or 1° F. in 57 miles.

*Range of mean temperature from January to July.*—The greatest range, 72°, is found in extreme North Dakota, and the least, 8°, at Eureka, Cal. San Francisco has 9°, Key West 14°, New York City 43°, Chicago 48°. The difference between the normal minimum and normal maximum temperature will also give an idea of changes in climate. This is only 7° at Tatoosh in January, 10° at San Francisco, 9° at Key West, 16° at Chicago, 14° at New Orleans and New York, 23° at Yuma, and 31°, highest in the country, at Pueblo, Col. In July these ranges are nearly the same, save that the highest, 36°, now appears at Fresno, in central California. In the latter case the very clear skies of the summer cause intense radiation of heat, and this accounts for the very great difference between the maximum and minimum.

*Individual temperatures.*—The lowest temperature at a regular station has been −55° F. in the extreme north of Montana, but this has been exceeded at Tobacco Garden, Dak., −60° F. At San Francisco, 29°; Chicago −20° (but once in twenty years); New York City, −6°; New Orleans, 15°; Key West, 41°; Washington, D. C., −14°.

The highest temperature observed at a regular station has been 118° F. at Yuma, though Furnace Creek has shown 122°; Mammoth Tank, 128°; San Francisco, 99°; Chicago, 100°; New Orleans, 97°; New York City, 100°; Washington, 103°.[1]

*Number of days below freezing in four cold months.*—In southern Florida, extreme southern Texas, and on the Pacific coast of southern California the temperature does not go below freezing on an average once a year. In Minnesota and North Dakota, 120 times; Chicago, 89; New Orleans, 5; Washington, D. C., 74; New York City, 82.

*Temperature above 90°, June, July, and August.*—In Minnesota and North Dakota, from 3 to 7 times; Yuma, 90 times; New Orleans, 28; St. Louis, 24; New York City, 4; Washington, 10; Key West, 3 times in five years.

*Moisture in the air.*—In January the least moisture (0.5 grain per cubic foot) is found in the extreme Northwest; this increases quite

[1] The highest ever observed, 104.4°, was due to a faulty shelter.

regularly to 4 gr. on the Gulf, 6.5 gr. at Key West, nearly 3 gr. on the Pacific, 2.1 gr. at Yuma, 1.3 gr. at Chicago, 1.6 gr. at New York City, and 1.7 gr. at Washington.

In July the Northwest has 5.5 gr. per cubic foot, increasing to 9 gr. on the Gulf. The lowest, 1.5 gr., is found at Winnemucca.

All through the region from the Rockies westward, except on the Pacific Coast the air is very dry, hardly reaching 3 gr. per cubic foot. Chicago has 5.7 gr.; New York City, 6.7 gr.; Washington, 7.0, gr.; and Key West, 9.1 gr. Corpus Christi has 9. 5 gr. the largest in the country.

*Precipitation.*—The annual precipitation, unlike the temperature varies in an east and west direction more than from north to south. The Atlantic Coast receives over 40 inches in the north and over 50 in the south. The lake regions have from 33 in. to 39 in., the Gulf Coast has about 60 in., but this diminishes toward the south. The extreme point of Texas has but 32 in., and Key West 41 in., while the Dry Tortugas in the Gulf have even less. The upper Missouri has about 15 in., as also the north and middle Rocky Mountain region. Yuma has 3 in.; San Diego, 10 in ; San Francisco, 23 in.; Portland, Oregon, 50 in.; and the rainiest part of the whole country is Northwestern Oregon. It is said that no successful crops can be raised where the annual fall is less than 19 in., but there are large areas in the Missouri and upper Mississippi valleys where there is less than this amount. A successful crop has been raised with an annual fall of but 7 in., in a region where there have been copious dews and where the rain has fallen during the growing season. It should be noted, however, that east of the Rockies there are regions in western Kansas and southwestern Nebraska where no more than three crops out of five may be assured without assistance from irrigation.

*Seasonal distribution.*—The most important question connected with precipitation is its amount during the growing season. On the Pacific Coast there are very marked winter rains, culminating in January, and almost no rain falls during the warmer months. An explanation of this has been given already. In the plateau region to the west of the Rockies the rain is irregularly distributed. In general the north half has a maximum in the spring, while the south half has it in July and August. In Texas the maximum occurs in September. On the Atlantic Coast the rain is quite evenly distributed, with a tendency to a slightly greater fall in August and September. Over the rest of the country there is a marked maximum in June and early July. This rain, coming as it does just at the height of the growing season, is of the highest importance. A careful study of the seasonal distribution of rain over central Europe and central Australia has shown exactly the same peculiarity—that is, a maximum in the warmest months. In order to determine whether the distribution of pressure, temperature, and winds brought about this result, as is plainly the case on the Pacific Coast,

monthly maps were made giving these conditions for both abnormally wet and dry months, and it was found that there were maps giving exactly the same mean pressure and wind direction for both dry and wet months. In addition to this, the fact that these conditions are similar over such widely separated regions shows that there must be some universal law acting, and that, too, independently of the pressure and wind. In the warmest months there is three or four times the moisture in the air that there is in the coldest—that is, east of the Rockies; hence a cooling of 20° would precipitate much more rain in the former than in the latter case. Add to this the fact that it is during the warmest months we have our thunder storms, during which almost all our rain at that season falls, and we have full explanation of this phenomenon. It should be noted that, in general, in summer a month with a temperature below the normal will always give a greater rainfall than one with a temperature above the normal.

*Rainy days.*—The average number of rainy days (days with .01 inch precipitation) in January is as follows: Mississippi Valley, 10; Upper Lakes, 12 to 18; Lower Lakes, 15 to 20; North Atlantic, 13; South Atlantic, 8 to 10; Gulf States, 11; Ohio Valley, 13 to 16. In July the Mississippi Valley has 10; Upper and Lower Lakes, 10 to 12; North Atlantic, 11; South Atlantic, 12 to 15; Gulf States, 9 to 15; Ohio Valley, 11. Nearly the whole country east of the Mississippi has fewer rainy days in summer, but the amount of rain is much greater than in winter.

*Clouds.*—The average cloudiness is about 55 per cent over the country in January, with over 70 per cent in the North Pacific States, 25 to 35 per cent South Pacific States, 40 per cent in the south plateau region, 45 per cent in the Missouri Valley, and 70 per cent in the Lower Lakes. In July there is a diminished cloudiness, about 45 per cent, with 40 to 50 per cent on Pacific Coast, 15 to 25 per cent in the interior near the Pacific, and 45 to 50 per cent on the Atlantic Coast. The diurnal range of clouds over the whole country shows a minimum about midnight and a maximum at 2 to 3 p. m.

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## 2.—THE CLIMATE OF THE WEST INDIES.

MAXWELL HALL.

Trinidad, Grenada, St. Vincent, Barbados, St. Lucia, Dominica, Antigua, and Jamaica are the principal British islands in the West Indies. They are all washed by the warm waters of the Gulf Stream, and they have in consequence much the same climate; and as careful observations have been made in Jamaica and Barbados for some years, it becomes possible, with the aid of notes from the other British islands,

to give a general sketch of the more prominent features of the meteorology of this part of the world.

*Temperature.*—Kingston, Jamaica, is a town containing about 40,000 inhabitants.[1] The rainfall there is small when compared with that of the island, and no doubt the dry and dusty streets have some effect on the temperature and its range. We shall therefore compare the Kingston results with those obtained by Dr. Walcott in a country district of Barbados:

| Month. | Kingston, Jamaica, results of 10 years' observations. | | | | Barbados, results of 20 years' observations. | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean. | Maximum. | Minimum. | Range. | Mean. | Maximum. | Minimum. | Range. |
| | ° | ° | ° | ° | ° | ° | ° | ° |
| January | 74.6 | 86.4 | 66.8 | 19.6 | 73.6 | 77.5 | 70.3 | 7.2 |
| February | 74.7 | 85.8 | 66.8 | 19.0 | 73.4 | 77.4 | 70.0 | 7.4 |
| March | 75.8 | 85.7 | 67.8 | 17.9 | 73.5 | 78.3 | 70.5 | 7.8 |
| April | 77.9 | 86.5 | 69.8 | 16.7 | 76.2 | 80.4 | 71.4 | 9.0 |
| May | 79.4 | 87.2 | 72.4 | 14.8 | 76.2 | 81.7 | 71.0 | 10.7 |
| June | 80.8 | 88.5 | 73.8 | 14.7 | 76.7 | 81.8 | 73.0 | 8.8 |
| July | 81.1 | 89.7 | 73.5 | 16.2 | 76.7 | 82.0 | 73.0 | 9.0 |
| August | 80.4 | 89.4 | 73.2 | 16.2 | 76.7 | 82.4 | 73.3 | 9.1 |
| September | 80.1 | 89.7 | 73.3 | 16.4 | 76.7 | 82.4 | 73.4 | 9.0 |
| October | 78.9 | 88.9 | 72.1 | 16.8 | 76.9 | 81.8 | 73.2 | 8.6 |
| November | 77.8 | 88.9 | 70.7 | 18.2 | 76.1 | 80.0 | 72.7 | 7.3 |
| December | 75.7 | 87.0 | 68.4 | 18.6 | 75.0 | 78.8 | 71.2 | 7.6 |
| Means | 78.1 | 87.8 | 70.7 | 17.1 | 75.6 | 80.2 | 72.0 | 8.2 |

It does not appear how Dr. Walcott obtained his mean temperature for the day, and no note is made as to instrumental errors or as to exposure. The Kingston mean temperature for the day was assumed to be the mean of the corrected eight-hourly readings at 7 a. m., 3 p. m., and 11 p. m. The instruments were exposed in a Stevenson's screen on a lawn, and their errors were taken from time to time by means of a standard thermometer.

The observations in Kingston were made at an elevation of about 50 feet above the sea level; those in Barbados were made at an elevation of 430 feet above the sea level; and from observations made in Jamaica among the mountains it appears that near the sea level the mean temperature decreases about 1° F. for every 315 feet; hence, the results for mean temperature reduced to sea level are:

| | ° F. |
|---|---|
| Kingston, Jamaica | 78.3 |
| Barbados | 77.0 |

The uniformity of temperature in Barbados is very remarkable. In the country districts of Jamaica the range is about 12° F.; the same in St. Lucia; in Grenada and Dominica about 10° F., and generally the range of temperature in the West Indies is about 12° F., instead of 8°, as at Barbados; of 15°, as at Trinidad; or of 17°, as at Kingston, Jamaica.

[1] This is for 1885, corresponding to the middle of the series of observations, whose results are given near the end of this article.

Hence we have for the West Indian Islands generally:

| | °F. |
|---|---|
| Mean temperature | 77.5 |
| Maximum temperature | 84.5 |
| Minimum temperature | 72.5 |
| Range | 12 |

The monthly variations of temperature are well shown in the table above. As to the diurnal variations, they are as varied as the circumstances of each locality, and according as sunshine, cloud, morning fog, afternoon rains, wind, and calms prevail, so will the characteristics of the diurnal variation change; but generally the minimum temperature occurs between dawn and sunrise. The temperature rises rapidly from 7 a. m. to 9 a. m., when the sea breeze sets in and checks the rate of increase. The maximum occurs between noon and 1 p. m. Clouds or rain keep the afternoons fairly uniform, but the clear evenings allow the temperature to fall at once, the minimum occurring, as already said, a little before sunrise.

It has been stated above that the mean temperature falls about 1° F. for every 315 feet, but if the fall of temperature be expressed in terms of the fall of barometric pressure it will be found that—

$$\text{Fall of mean temperature} = 2.92^\circ\ (\text{fall of pressure}) + 0.08^\circ\ (\text{fall of pressure})^2$$

This formula gives the limit of perpetual snow at 14,000 feet, as in Abyssinia,[1] and it is probably accurate enough for the small elevations in the West Indian islands; but as the same process has to be gone through with maximum and minimum temperatures, it will perhaps be better to give the following table, showing the decrease of temperature with elevation in Jamaica:

| Station. | Elevation. | Barometric pressure. | Temperature. | | | |
|---|---|---|---|---|---|---|
| | | | Mean. | Maximum. | Minimum. | Range. |
| | *Feet.* | *Inches.* | ° | ° | ° | ° |
| Kingston | 50 | 29.95 | 78.1 | 87.8 | 70.7 | 17.1 |
| Kempshot | 1,773 | 28.20 | 72.7 | 80.5 | 68.0 | 12.5 |
| Cinchona Plantation | 4,907 | 25.27 | 62.6 | 68.5 | 57.5 | 11.0 |
| Portland Gap | 5,477 | 24.71 | 59.7 | 69.0 | 54.6 | 14.4 |
| Blue Mountain Peak | 7,423 | 23.14 | 55.7 | 71.1 | 46.8 | 24.8 |

It will be noticed that while the mean and minimum temperatures decrease with more or less regularity, the maximum does not fall when an elevation of 5,000 feet is reached, within our very limited scope of observation. Consequently the range increases, and for all health purposes a moderate elevation of 2,000 feet is as good as the highest obtainable in these islands. The highest and lowest temperatures recorded in Kingston, Jamaica, since 1880, when regular observations were commenced, are 96.7° F. and 56.7° F., respectively.

*Vapor.*—The climate of the West Indies is both warm and moist, and we have now to consider the latter quality.

[1] The same latitude as the West Indies.

In the following table for Kingston, Jamaica, the minimum temperatures are reproduced in order to compare them with the temperature of the dew-point:

| Month. | Minimum. | Dew-point. | Humidity. |
|---|---|---|---|
| | ° *F.* | ° *F.* | *Per cent.* |
| January | 66.8 | 66.7 | 78 |
| February | 66.8 | 66.7 | 78 |
| March | 67.8 | 67.6 | 77 |
| April | 69.8 | 69.1 | 75 |
| May | 72.4 | 71.4 | 78 |
| June | 73.8 | 72.8 | 78 |
| July | 73.5 | 72.5 | 76 |
| August | 73.2 | 73.0 | 79 |
| September | 73.3 | 73.1 | 80 |
| October | 72.1 | 72.2 | 81 |
| November | 70.7 | 70.1 | 78 |
| December | 68.4 | 68.0 | 78 |
| Mean | 70.7 | 70.3 | 78 |

In Jamaica, therefore, the temperature falls at night until the dew-point is reached; then dew is deposited, latent heat is given out, and the further fall of temperature is arrested. On still nights the amount of dew is sometimes very large. At the Kempshot Observatory, Jamaica, it is seen and heard to drip off the painted canvas roof like rain after a shower, and although in Scotland dew may chiefly come up from the ground, yet in the West Indies dew chiefly comes down from the air.

The humidity, it will be noticed, is large and constant; and after what has been said about Kingston and its small rainfall it will be a matter of surprise to find that other islands are drier. Take Dominica, for instance, where there is a very heavy rainfall. Among some notes sent me by the commission the following occurs: "Although the rainfall is so heavy there is very little dampness, and there is a peculiar absence of mildew and rust." Among the hills in Jamaica there is a heavy rainfall, the air is very damp, and it is very difficult to preserve books, clothes, and steel instruments, on account of mildew and rust. Unfortunately, vapor does not seem to have attracted Dr. Walcott's attention in Barbados, but in Grenada, while the mean dew-point for the years 1891 and 1892 was 70.4°, which agrees almost exactly with the Kingston result, yet as the minimum temperature was as high as 74°, the humidity was only 72 per cent; in Barbados the dew-point was about 70.6° in 1892, the minimum was 74.8°, and the humidity was only 70 per cent, and so on.

The humidity of Kingston is therefore due to the fact that the minimum temperature falls to that of the dew-point; or, in other words, Kingston is damper than Barbados because it is much cooler at night and allows much dew to be formed.

In Trinidad also the minimum temperature falls below the dew-point and the humidity is in consequence as large as 77 per cent.

Consequently while the mean dew-point must be about 70.3° for the West Indies, the humidity is probably about 74 per cent.

Corresponding with a dew-point of 70.3° there is a vapor tension of 0.741 inch; and the effects of this large amount of vapor are various and important. Dew and the arrest of falling temperature have been already mentioned; to these must be added the gorgeous hues of the sky at sunrise and sunset and the blue tint of distant mountains; the absence of sunstroke and the relaxing effect of prolonged residence; the deterioration or destruction of goods stored for any length of time and the rapid decomposition of dead organic matter.

Humidity, considered apart from the amount of vapor in the air, and the dryness of the air, or 100 per cent minus the humidity, are important elements in daily life and in the consideration of certain diseases, consumption for instance; but while the dew-point, or the amount of vapor, hardly varies during the day, the variation of the humidity is very considerable. In Jamaica we have at—

| | Per cent. |
|---|---|
| 7 a. m | 81 |
| 3 p. m | 68 |
| 11 p. m | 85 |
| Mean | 78 |

These results apply to the air 4 feet 6 inches above the ground; nearer the ground the humidity increases at night up to 100 per cent.

*Rainfall.*—Barbados is a small, low-lying island. The average annual rainfall there is 60 inches.

St. Vincent, St. Lucia, and Dominica are small mountainous islands near Barbados. Their average rainfall is about 100 inches.

Antigua and Trinidad are small islands of moderate elevation. The rainfall at Antigua is only 46 inches; that at Trinidad about 65 inches.

Jamaica is a much larger island than any of the above mentioned. Its surface is highly diversified with lofty mountains, hills, and plains, and its annual rainfall is 67 inches, which is almost exactly the mean of the results given above.[1]

February is the driest month in the West Indies. In Jamaica the dry months are February and March. In Barbados, Dominica, and Trinidad, February, March, and April. In St. Lucia and Antigua, February, March, April, and May. This is remarkable, for in Jamaica there is a large rainfall in May.

The summer and autumn months are wet, especially October. In the following table (p. 594) are given the results of observations extending over forty-five years in Barbados and twenty years in Jamaica. The observations were taken on an average at about 90 stations in each island.

[1] At Nassau, in New Providence, the rainfall is 48 inches; but at Turks Islands, at the other end of the Bahamas, the rainfall is only about 25 inches. The islands are all low-lying; and in the Turks Islands advantage is taken of the small rainfall to produce salt in large quantities by the evaporation of sea water in shallow tanks.

*Monthly rainfall.*

| Month. | Jamaica. | Barbados. |
|---|---|---|
| | *Inches.* | *Inches.* |
| January | 4.12 | 3.38 |
| February | 2.44 | 2.33 |
| March | 2.92 | 1.79 |
| April | 3.72 | 2.28 |
| May | 9.06 | 3.45 |
| June | 6.26 | 5.50 |
| July | 4.81 | 5.91 |
| August | 6.74 | 7.45 |
| September | 6.86 | 7.32 |
| October | 9.06 | 8.26 |
| November | 5.90 | 7.52 |
| December | 5.59 | 4.84 |
| Year | 66.98 | 60.24 |

There are no long-continued droughts or flood rains in the West Indies.

Jamaica is naturally divided into four rainfall divisions. The northeastern and northern divisions have winter rains in November, December, and January. These rains are brought by the east or northeast winds, and fall day and night. The northeastern and west central divisions have summer rains. These rains come as a rule during the summer afternoons from enormous cumulus clouds piled up to the height of 5 or 6 miles, and they are accompanied with much thunder and lightning. The southern division is dry, having rains for the most part only during the May and October "seasons."

Now, it so happens that when Dr. Hans Sloane[1] was in Jamaica as physician to the Duke of Albemarle, governor of Jamaica in the year 1687, he noticed the May and October rains—the winter rains on the north side, the summer rains on the central hills, and the small rainfall on the southern plains. Consequently the chief characteristics of the Jamaica rainfall have not altered for two hundred years.

It is therefore to such a constant and uniform climate that we must look for the solution of certain problems. Let us take, for instance, the supposed connection between the rainfall and the sun-spot period.

The irregularities of the rainfall from year to year are so large that apparently there is no connection whatever between the sun-spot period and the Jamaica or any other rainfall; but if we smooth down these irregularities by taking the mean for three years as the rainfall for the middle of those years—that is to say, if we take the mean of the rainfall during 1866, 1867, and 1868 as applying to the middle of 1867, the mean of the rainfall during 1867, 1868, and 1869 as applying to the middle of 1868, and so on—we shall then get a series which rises to a maximum about the time of a sun-spot minimum, and which falls to a minimum about the time of a sun-spot maximum.

The Barbados and Antigua rainfalls have been subjected to the same treatment, with the same results; but it will be noticed that the

[1] Afterwards Sir Hans Sloane, the founder of the British Museum.

smoothed Jamaica rainfall rises and falls with much greater regularity than the smoothed Barbados and Antigua rainfalls, probably in consequence of the larger area of Jamaica.

The Antigua rainfall is based upon observations made at about 47 stations.

The rainfall at the Botanic Gardens, Trinidad, is also given. The great irregularities are due to the circumstance that the results are based on one station instead of many.

*Sun-spot period and the rainfall.*

| Year (middle of). | Sun-spot period. | Jamaica (90 stations). | | Barbados (90 stations). | | Antigua (47 stations). | | Trinidad (1 station). | |
|---|---|---|---|---|---|---|---|---|---|
| | | Rainfall. | Average for 3 years. | Rainfall. | Average for 3 years. | Rainfall. | Average for 3 years. | Rainfall. | Average for 3 years. |
| | | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* | *Inches.* |
| 1843 | Min.. | | | 45.81 | | | | | |
| 1844 | | | | 74.45 | 54.56 | | | | |
| 1845 | | | | 43.91 | 61.39 | | | | |
| 1846 | | | | 65.82 | *52.61 | | | | |
| 1847 | | | | 48.10 | 59.23 | | | | |
| 1848 | Max.. | | | 63.77 | 54.88 | | | | |
| 1849 | | | | 52.77 | 61.47 | | | | |
| 1850 | | | | 67.88 | 60.02 | | | | |
| 1851 | | | | 59.40 | 62.02 | | | | |
| 1852 | | | | 58.77 | 62.34 | | | | |
| 1853 | | | | 68.84 | 59.50 | | | | |
| 1854 | | | | 50.88 | †65.68 | | | | |
| 1855 | | | | 77.31 | 58.89 | | | | |
| 1856 | Min .. | | | 48.49 | 62.23 | | | | |
| 1857 | | | | 60.90 | 51.54 | | | | |
| 1858 | | | | 45 22 | *53.45 | | | | |
| 1859 | | | | 54.22 | 52.45 | | | | |
| 1860 | Max.. | | | 57.91 | 61.98 | | | | |
| 1861 | | | | 73.82 | 63.97 | | | | |
| 1862 | | | | 59.27 | 58.49 | | | 63.15 | |
| 1863 | | | | 42.38 | 53.61 | | | 66.80 | 64.28 |
| 1864 | | | | 59.19 | 56.74 | | | 62.90 | 71.66 |
| 1865 | | | | 68.64 | 62.50 | | | 85.28 | †72.01 |
| 1866 | | 53.65 | | 59.68 | †66.08 | | | 67.86 | 73.23 |
| 1867 | Min .. | 64.47 | 61.95 | 69.93 | 58.07 | | | 66.56 | 63.54 |
| 1868 | | 67.74 | 62.58 | 44.60 | 54.35 | | | 56.21 | 58.74 |
| 1869 | | 55.37 | †70.85 | 48.52 | 51.10 | | | 53.46 | 59.67 |
| 1870 | Max.. | 89.43 | 64.96 | 60.17 | 50.05 | | | 69.35 | 66.13 |
| 1871 | | 50.09 | 61.57 | 41.46 | 50.06 | | | 75.58 | 64.96 |
| 1872 | | 45.18 | *52.78 | 48.55 | *47.23 | | | 49.95 | 56.52 |
| 1873 | | 63.06 | 59.06 | 51.69 | 53.15 | | | 44.02 | *56.75 |
| 1874 | | 68.94 | 61.47 | 59.22 | 57.54 | 31.16 | | 76.28 | 60.40 |
| 1875 | | 52.42 | 64.24 | 61.71 | 57.89 | 28.78 | 33.97 | 60.90 | 73.04 |
| 1876 | | 71.35 | 64.06 | 52.73 | 62.85 | 41.98 | 39.94 | 81.95 | †71.65 |
| 1877 | | 68.40 | 72.06 | 74.10 | 66.64 | 49.05 | 46.05 | 72.10 | 71.43 |
| 1878 | | 76.42 | †77.89 | 73.10 | 73.83 | 47.11 | 52.55 | 61.24 | 66.26 |
| 1879 | Min .. | 88.84 | 73.57 | 74.30 | †72.79 | 61.50 | 52.77 | 65.43 | 69.67 |
| 1880 | | 55.44 | 70.96 | 70.98 | 71.91 | 49.69 | †54.98 | 82.34 | †71.16 |
| 1881 | | 68.60 | 60.64 | 70.45 | 63.83 | 53.75 | 45.49 | 65.72 | 67.02 |
| 1882 | | 57.87 | 61.91 | 50.06 | 61.21 | 33.04 | 47.43 | 52.99 | 63.07 |
| 1883 | | 59.26 | 58.01 | 63.12 | 57.04 | 55.51 | *44.13 | 70.50 | 60.12 |
| 1884 | Max.. | 56.90 | *58.67 | 57.95 | *55.05 | 43.98 | 47.63 | 56.88 | *56.87 |
| 1885 | | 59.86 | 69.12 | 44.08 | 61.61 | 43.39 | 45.05 | 43.22 | 62.31 |
| 1886 | | 90.61 | 73.71 | 82.81 | 65.30 | 47.78 | 44.95 | 86.82 | 64.71 |
| 1887 | | 70.66 | †77.79 | 69.01 | 73.64 | 43.68 | 45.23 | 64.09 | 72.12 |
| 1888 | | 72.11 | 72.31 | 69.09 | †71.67 | 44.23 | †53.83 | 65.44 | 67.77 |
| 1889 | Min . | 74.15 | 70.23 | 76.92 | 66.18 | 73.59 | 50.27 | 73.79 | †74.04 |
| 1890 | | 64.42 | 74.42 | 52.53 | 65.25 | 33.00 | 52.20 | 82.90 | 70.14 |
| 1891 | | 84.70 | 74.03 | 66.30 | | 50.01 | 40.51 | 53.74 | 75.93 |
| 1892 | | 72.98 | | | | 38.53 | | 91.14 | |

* Minimum. † Maximum.

*The winds.*—The foregoing account of the high temperature, the large amount of vapor, and the heavy rains apparently indicate a most objectionable climate, and so no doubt it would be without the

winds, which entirely change the conditions. This is not a matter of speculation, for when a cyclone passes on its northwesterly course to the north of Jamaica the winds in Jamaica are held in check for two or three days and then the weather becomes very dull and oppressive.

The winds in the West Indies are governed by the great and permanent anticyclone which exists in the North Atlantic, about half way between the Azores and Antigua, so that as a rule east to northeast winds prevail. The North American continent produces variations, according to the time of the year, and when that continent is very hot the wind sweeps over Jamaica from the east-southeast, the average direction being otherwise east-northeast.

These east-northeast winds are of course met with at sea, and their diurnal variation is very remarkable. This variation is apparently the same as what is known as the "sea breeze" on the larger islands; that is to say, they begin to blow freshly between 9 and 10 a. m., reach a maximum about 1 p. m., and then gradually subside. At sea they blow gently through the night; on the islands they encounter or combine with the "land breeze" at night.

At Barbados, St. Lucia, and Jamaica, about 240 miles of east-northeast "trades" pass over during the twenty-four hours.

Kingston, Jamaica, is well situated for the study of the sea breeze, but badly situated for the study of the east-northeast "trades;" the "trades" are found at any exposed place 1,000 feet above the sea level.

In Kingston the continuous self-recording instruments show that about 89 miles of wind[1]—sea breeze, checked "trades," and land breeze combined—pass during the twenty-four hours. We are concerned with both the amount and the diurnal variation of this wind.

*Diurnal variation of the wind.*

| | Miles per hour. | | Miles per hour. |
|---|---|---|---|
| 1 a. m | 1.8 | 1 p. m | 7.6 |
| 2 a. m | 1.9 | 2 p. m | 7.6 |
| 3 a. m | 2.0 | 3 p. m | 7.1 |
| 4 a. m | 2.0 | 4 p. m | 6.6 |
| 5 a. m | 1.9 | 5 p. m | 5.7 |
| 6 a. m | 2.0 | 6 p. m | 4.5 |
| 7 a. m | 2.1 | 7 p. m | 3.4 |
| 8 a. m | 2.1 | 8 p. m | 2.7 |
| 9 a. m | 2.7 | 9 p. m | 2.2 |
| 10 a. m | 4.3 | 10 p. m | 1.9 |
| 11 a. m | 5.8 | 11 p. m | 1.8 |
| Noon | 6.9 | Midnight | 1.8 |

The constancy from 9 p. m. through the night to 8 a. m. is very remarkable, and there is no lull or calm at all between the southeast sea breeze and the north land breeze. The land breeze commences about 9 p. m. and continues until 6 or 7 a. m.

[1] This was on the roof of the colonial secretary's office.

The sea breeze from 10 a. m. to 5 p. m. is really very invigorating, and this interval, of course, coincides with the chief business hours in Kingston. It is surprising to think that the figures in the table above contain the necessary conditions for health and vigor referred to at the commencement of this section.

*Clouds.*—During the winter months there is much detached stratus; during the summer months there is much cumulus, which keeps the afternoons cool, especially as the cumuli soon degenerate into strato-cirrus and then disappear, leaving the nights perfectly clear.

*Cirrus.*—The lower limit must be about 3 miles, as the freezing point of water will generally be found at this elevation. Cirrus is often seen in the morning about sunrise during the summer and autumnal months, but they rapidly disappear as the temperature increases. Under these circumstances they are fine-weather clouds, and it is only when they increase in extent and develop into cirro-stratus that they indicate the approach of bad weather. According to the following table, which is based on observations in Jamaica during the autumnal months, there seems to be a well-marked upper current from the east-northeast:

*Cirrus: average drift from—*

| | | | |
|---|---|---|---|
| N | 7 | SW | 7 |
| NE | 26 | W | 13 |
| E | 28 | NW | 7 |
| SE | 8 | | |
| S | 4 | | 100 |

Cirro-stratus also shows the existence of the east-northeast current:

*Cirro-stratus: average drift from—*

| | | | |
|---|---|---|---|
| N | 9 | SW | 6 |
| NE | 25 | W | 5 |
| E | 27 | NW | 4 |
| SE | 18 | | |
| S | 6 | | 100 |

It is to be noticed that the west has an unduly large percentage for cirrus, but not for cirro-stratus. I believe that cirrus being at very great altitudes is influenced at times by storm centers too far north of Jamaica to affect the lower cirro-stratus.

*Strato-cirrus.*—When rain begins to fall from a large cumulus a quantity of cloud is poured into the air from the top of the cumulus as smoke from a factory chimney. This takes place in all parts of the world when rain falls from cumulus, but in the temperate zones only a little *false cirrus*, or cirri-form cloud, is thrown off. In Jamaica the process is on a gigantic scale, and the cloud is spread out as a sheet far and wide so as to shade the land for an hour or two from the direct rays of the afternoon sun. It is therefore a common cloud in Jamaica. Its texture at first is thick and woolly, but as it spreads the sheet becomes thinner. It then generally settles down into irregular cumulo-cirrus,

into alto-stratus, and finally it disappears a little after sunset, leaving the evening sky perfectly clear.

Now, by means of a sextant, some careful observations were made of the altitudes of the tops of well-formed cumuli whose distances could be ascertained by their rain falling on mountain ranges or by the average interval between the distant thunder and lightning, and it was found that the average height of such well-formed cumuli during the autumn months was as much as 6 miles. At this elevation the temperature is below zero, and strato-cirrus when spread out as described above must be very fine snow, as distinguished from the very minute particles of ice which form cirrus and cirro-stratus, which falls slowly by its own weight.

There are no indications of any upper return currents from the equator to the north pole.

*General notes.*—Thunderstorms occur during the summer months on a grand scale, and the quantity of electricity discharged in each flash of lightning seems very large; an interval of eighty seconds may often be noticed between a flash and its report. Along the whole central line of hills in Jamaica[1] heavy rains, accompanied by thunderstorms, occur every afternoon from the beginning of May to the end of October. Lightning does but little damage, as it can easily "make earth" with the aid of trees drenched by the rain.

Cyclones at times during the hurricane months of August, September, and October break the monotony of the West Indian weather. They apparently commence as rings of wind around a large and calm center, where the barometric pressure is perhaps two-tenths of an inch below that of the surrounding air. The ring moves onward with the general drift to the west-northwest, and the action either increases or dies out. As to the origin of the rings, we must, in general, look to the heavy rains which fall from an irregular extension of the equatorial calms which occur east of the West Indies far enough north during the hurricane months, and during those months only, to allow the differential effect of the earth's rotation on moving currents to give the necessary whirl. The cyclonic limit is between latitudes 10° and 12°.

Earthquakes occur and are sometimes very disastrous. It is found in Jamaica that the wind is affected some hours before a shock, and that stratus is often formed after a shock; also, that the barometer is affected.[2] The only explanation I can give at present is that the land gradually rises and disturbs the level of the sea and air; this would, under certain circumstances, check the easterly wind, disturb the barometer, and produce cloud, and, of course, while upheaval is going

[1] A curious mistake occurs in Sir John Herschel's Meteorology. (Reprint from Encyc. Brit., 2d ed., p. 135.)

[2] A very fine continuous photographic record of the mercurial column (mechanically reduced to 32° F.) is now being made in Kingston in order, if possible, to solve this and other problems.

on there must be great subterraneous strain, and any sudden giving way of the geological strata would produce the earthquake shocks. The temperature on the whole is not affected, although it has been known for over two hundred years that the weather before an earthquake seems unusually hot and oppressive; this effect is simply due to the stopping of the wind.

We shall, in conclusion, consider some matters connected with the health of Kingston, Jamaica. In the following table all the meteorological results are given, as well as the average number of deaths in Kingston from a few groups of diseases:

*Kingston meteorological results, etc., for the ten years from June, 1880, to May, 1890, inclusive.*

| Month. | Barometric pressure (sea level 32° F.). | Temperatures. | | | | Wind S. E. (miles per diem). | Vapor. | | Cloud per cent. | Rainfall. | | Infantile diseases. | Lung diseases. | Fever. | Dysentery and diarrhea. | Various. | Total. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean. | Maximum. | Minimum. | Range. | | Dew-point. | Humidity. | | Kingston. | The Island. | | | | | | |
| | *Inches.* | ° | ° | ° | ° | | ° | | | *Ins.* | *Ins.* | | | | | | |
| Jan | 30.054 | 74.6 | 86.4 | 66.8 | 19.6 | 68 | 66.7 | 78 | 29 | 0.96 | 3.87 | 21 | 19 | 10 | 9 | 58 | 117 |
| Feb | 30.049 | 74.7 | 85.8 | 66.8 | 19.0 | 72 | 66.7 | 78 | 27 | 0.82 | 2.62 | 24 | 14 | 8 | 12 | 53 | 111 |
| Mar | 30.034 | 75.8 | 85.7 | 67.8 | 17.9 | 77 | 67.6 | 77 | 29 | 1.59 | 2.88 | 32 | 17 | 7 | 15 | 68 | 139 |
| Apr | 30.008 | 77.9 | 86.5 | 69.8 | 16.7 | 68 | 69.1 | 75 | 39 | 1.02 | 4.18 | 27 | 16 | 9 | 15 | 55 | 122 |
| May | 29.979 | 79.4 | 87.2 | 72.4 | 14.8 | 74 | 71.4 | 78 | 56 | 6.00 | 8.40 | 22 | 15 | 8 | 14 | 60 | 119 |
| June | 30.000 | 80.8 | 88.5 | 73.8 | 14.7 | 115 | 72.8 | 78 | 57 | 5.51 | 7.83 | 16 | 14 | 9 | 11 | 54 | 104 |
| July | 30.024 | 81.1 | 89.7 | 73.5 | 16.2 | 103 | 72.5 | 76 | 52 | 2.15 | 4.32 | 18 | 18 | 11 | 7 | 57 | 111 |
| Aug | 29.983 | 80.4 | 89.4 | 73.2 | 16.2 | 80 | 73.0 | 79 | 55 | 4.09 | 6.83 | 12 | 15 | 9 | 4 | 50 | 90 |
| Sept | 29.956 | 80.1 | 89.7 | 73.3 | 16.4 | 70 | 73.1 | 80 | 62 | 3.59 | 6.86 | 11 | 12 | 7 | 2 | 47 | 79 |
| Oct | 29.937 | 78.9 | 88.9 | 72.1 | 16.8 | 56 | 72.2 | 81 | 58 | 4.69 | 7.84 | 13 | 14 | 7 | 4 | 54 | 92 |
| Nov | 29.962 | 77.8 | 88.9 | 70.7 | 18.2 | 53 | 70.1 | 78 | 44 | 1.22 | 5.07 | 17 | 15 | 10 | 4 | 57 | 103 |
| Dec | 30.005 | 75.7 | 87.0 | 68.4 | 18.6 | 57 | 68.0 | 78 | 38 | 1.50 | 5.60 | 16 | 16 | 10 | 6 | 59 | 107 |
| Means | 29.999 | 78.1 | 87.8 | 70.7 | 17.1 | 89 | 70.3 | 78 | 55 | ...... | ...... | 19 | 15 | 9 | 9 | 56 | 108 |
| Totals | ...... | ...... | ...... | ...... | ...... | .... | ...... | .... | .... | 32.64 | 66.30 | .... | .... | ... | .... | .... | .... |

*Infantile diseases.*—Under this heading is given the number of deaths in Kingston each month of the year from infantile diseases *not otherwise specified* in the books of the registrar-general. By comparing the numbers in this column with the total monthly numbers in the last column, it will be seen that the former are fairly proportional to the latter, although, indeed, their variation from their mean or average is larger. Consequently whatever cause systematically affects the total monthly numbers, the same cause affects young children rather than adults.

*Total monthly number.*—The total number of deaths varies on the average with considerable regularity from month to month; the maximum, 139, occurs in March; the minimum, 79, occurs in September. This variation is intimately connected with the temperature; and remembering that there must always be a considerable interval of time between such a cause and such an effect, it appears that the maximum occurs after the lower temperatures, and that the minimum occurs after the higher temperatures; or in other words, the death rate greatly increases after our cool season, and greatly diminishes after our warm

season. As in the year 1881 there were in Kingston only 5,000 white people out of a total population of 38,566, it is to the black and colored people that the above result chiefly applies; and again, as the fall of temperature during the cooler months is really very small, the large increase in the number of deaths must be chiefly due to the lives led by many of the poorest people—to their sleeping under open sheds and dilapidated roofs; and it would therefore seem possible to reduce the Kingston death rate in the course of time.

*Fever.*—There are but few deaths from this cause, and they are distributed throughout the year with considerable uniformity. One maximum occurs in July, after the May rains, and another occurs in November, December, and January, after the October rains. These maxima are due to malaria set free by the drying up of the ground after heavy rains. In many countries in the tropical parts of the earth it is dangerous to disturb the soil—as, for instance, in the Gold Coast Colony, in Africa—because the soil teems with malaria; and so it must have been in the earlier days of Jamaica, when the land was first cleared of forests and when the soil was first turned up for the cultivation of the sugar cane; but now we, for the most part, only feel the effect of water returning upward from considerable depths below the surface of the ground, for with the water ascend those specific disease germs which produce malarial fever when they can secure a footing in the blood and develop specific organisms.

"The germs of these organisms float about in the air from place to place and gain positions enabling them to enter the blood of some animal organism, say man, where they can grow and flourish, provided they are able to successfully encounter their mortal foes, the white corpuscles of the blood. If these white corpuscles are strong and vigorous, they will overpower the foreign growth and kill it. If, on the other hand, they are weak and feeble, and the germs very numerous, the foreign growth may get a secure footing and spread luxuriantly, changing the character of the fluids of the body, coagulating, it may be, the albumen, and otherwise setting up the unnatural and abnormal display of functions which we call disease."[1]

We have thus dwelt upon the cause of malaria in places which may be far removed from swamps and morasses, not on account of its importance to Kingston, but because of its widely spread influence.

But there has been a marked diminution in the intensity and prevalence of fevers in Jamaica during the last fifteen years; and, unless I am mistaken, there has been the same diminution in all the British West Indian islands.

*Lung diseases.*—The number of deaths from this cause is tolerably constant throughout the year. A maximum occurs in January, and another in July, but after both these maxima there seems to be a small reaction, and the minima speedily follow.

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[1]Nature, Lond., vol. 31, p. 267.

*Dysentery and diarrhea.*—Deaths from these diseases are intimately connected with the minimum temperature. A few cold nights in Kingston are certain to produce either or both these diseases, and their virulence depends upon the extent to which the temperature falls.

But some allusion must be made to predisposing causes, of which rain seems to be the most important in Jamaica. The people get wet and do not change their clothes; a cold night sets in, and disease is the immediate consequence. Thus there were rains in December, 1880, which produced dysentery and diarrhea in January, 1881, but it was not until the cold nights of January that these diseases became serious and caused the death of 72 persons during the three following months. Again in December, 1881, and the early part of 1882 there were no rains and very little dysentery and diarrhea.

We must not expect to find complete agreement between our meteorological returns and those of the registrar-general, but we hope that the outlines of the agreement have been correctly sketched, and that the importance of the subject has been duly pointed out.

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## 3.—THE CLIMATE OF THE CITY OF MEXICO.

MARIANO BÁRCENA.

*Introduction.*—Peculiar geographical and hypsometric conditions combine in the plateau of Mexico to neutralize each other and produce a mild and agreeable climate.

The City of Mexico, having a height of 2,265 meters above the sea, might be expected to suffer the usual severe cold of great altitudes, while elsewhere the latitude of 19° would insure a tropical heat; but the union of these determining causes yields a mean annual temperature of only 15.4° C., while there are no intolerable extremes. The maxima continue only a few hours in the middle of the day, and the minima an equal space of time in the early morning and the difference between them is not so great as in most other countries.

In Mexico the diurnal variation of temperature may be considered great, while the annual variation is slight. And these diurnal oscillations are the agreeable feature of the climate, for the temperature of a winter morning, even though a few degrees below 0° C., soon passes into the agreeable warmth of the day, while the noon heats of summer last but a few hours, and the mornings and evenings are always cool.

Such are the general laws regulating the temperature of the City of Mexico. These are occasionally modified for short periods by rains and by the Gulf storms, which, impelled by persistent winds along determinate routes, penetrate inland as far as the central plateau.

As the fluctuations of temperature are the clearest index to the character of a climate, I will now pass in review the thermometric

data obtained from observations made in the Central Meteorological Observatory of the City of Mexico during the space of sixteen years (1877 to 1892), the observations being personal, direct, and hourly, according to the practice of that office from its foundation to the present time.

In the examination of these data we shall see the general course traced by the temperature through all the months of the year; and next we shall note some of the relations of the other meteorological elements which principally influence the deviation from the laws already stated.

## Part I.

*Data relative to the temperature of the City of Mexico, deduced from the means of sixteen years.*

I.—*Mean monthly temperatures under shelter (degrees C.).*

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° 12.1 | ° 13.7 | ° 15.9 | ° 17.7 | ° 18.1 | ° 17.6 | ° 16.9 | ° 16.6 | ° 16.1 | ° 14.8 | ° 13.5 | ° 12.0 |

As is seen, the mean monthly temperature varied from 12° C. in December to 18.1° C. in May. It goes on rising from January to May, falling gradually from May to June, and during three months to September maintains, with small differences, almost a uniform degree; makes a new descent from September to October, and continues to go down till December. The resulting annual oscillation is 6.1° C., and it is relatively small from month to month.

II.—*Mean monthly temperatures in the open air.*[1]

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° 12.6 | ° 13.6 | ° 16.6 | ° 17.3 | ° 17.9 | ° 17.5 | ° 16.8 | ° 16.3 | ° 16.0 | ° 14.7 | ° 13.7 | ° 12.5 |

The movement here follows a course identical with the preceding; and it should be noted that, in consequence of the diurnal compensations to which we have already referred, the limits of temperature obtained in the open air are analogous to the corresponding ones observed under shelter.

III.—*Maximum shade temperatures.*

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° 25.0 | ° 26.8 | ° 28.8 | ° 31.6 | ° 30.0 | ° 29.5 | ° 28.0 | ° 28.9 | ° 28.5 | ° 25.6 | ° 25.1 | ° 23.0 |

[1][The expression "à l'intemperie"—translated, "in the open air"—evidently means unprotected from sunshine and terrestrial radiation, and is nearly equivalent to "radiation thermometer."—C. A.]

These are the highest indications which have been noted for each month in the period of sixteen years. As is seen, the absolute maximum temperatures in the shade have varied from 23° C. (December) to 31.6° C. (April). They have followed a course analogous to that of the mean temperatures, rising after January; but the maximum was reached in April, because generally the rains occur in May, lowering the temperature, while in April the hot and dry winds from the south prevail. Yet the maximum temperatures, like the others indicated, show a period of small variation in the summer months, and then fall quite rapidly until December.

IV.—*Absolute maximum temperatures in the open air.*

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° 41.8 | ° 37.7 | ° 41.7 | ° 44.4 | ° 44.9 | ° 47.5 | ° 42.8 | ° 45.6 | ° 40.2 | ° 42.2 | ° 42.8 | ° 46.7 |

The maximum temperatures in the open air deviate in some months from the course followed by the other data which we have just reviewed, a fact which is explained by the presence of disturbing phenomena like the passing of clouds, change of direction of the winds, etc. As is natural, the maxima tend to increase with the length of the days; but in the months of July and August the rains and the frequent passage of clouds between 2 o'clock and 4 o'clock in the afternoon hinder this rising, and on this account new anomalies appear in the last months of the year whose phenomena are not surprising in the maxima which we are comparing, because we are dealing with isolated extremes, distributed over the various years to which reference is made.

V.—*Minimum temperatures under shelter.*

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° —1.2 | ° 1.0 | ° 0.0 | ° 4.3 | ° 5.8 | ° 7.4 | ° 7.5 | ° 8.2 | ° 8.2 | ° —2.3 | ° —1.0 | ° —1.7 |

With few exceptions, the minimum temperature under shelter follows the general law as to the rise in the spring, the small variation in summer, and the rapid descent from the autumn to the winter. As is seen, the fall under shelter is not very appreciable, since it does not reach 2° C. below zero.

VI.—*Minimum temperatures in the open air.*

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° —4.4 | ° —1.9 | ° —0.8 | ° —1.6 | ° 3.1 | ° 2.4 | ° 3.3 | ° 3.9 | ° 2.5 | ° —2.5 | ° —5.6 | ° —7.2 |

Anomalies like those of the open-air maxima, and due to analogous causes, are noted in the minima in the open air. The lowest temperature observed, —7.2° C., only in the single year 1878, is presented as a really exceptional case, since the climate of the City of Mexico is not subject to great falls of temperature.

VII.—*Maximum diurnal variations observed for each month.*

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° 18.9 | ° 21.3 | ° 22.9 | ° 22.3 | ° 20.7 | ° 17.9 | ° 17.4 | ° 18.3 | ° 20.8 | ° 17.4 | ° 18.9 | ° 19.7 |

These figures are quite different from the variations in the preceding table, being greatest in the spring, when the greatest maxima occur; consequently, the extent of the oscillation depends rather upon this meteorological element than upon the low temperature of the cooler months, since its range is always increased more by a rise than by a fall of temperature, when the observation is made under shelter. Not so with the oscillations in the open air, which present various anomalies, due to causes analogous to those which produce the irregularity of the course of the maximum temperatures in the open air. The maximum annual oscillations observed in sixteen years are 32.6° C. for the shade and 56.4° C. for the open air.

VIII.—*Mean monthly temperature of the ground at the depth of 0.85 meter.*

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° 13.3 | ° 13.7 | ° 14.9 | ° 15.8 | ° 16.7 | ° 17.5 | ° 17.2 | ° 16.9 | ° 16.2 | ° 15.6 | ° 15.0 | ° 14.6 |

This temperature presents a gradual ascent in the first half of the year and a fall in the six following months; its minimum occurs in January and the maximum in June. Note, furthermore, that in February the mean temperatures of the ground and of the air in the shade are the same; that in general there is but a slight difference between the two in any given month, the temperatures of the ground being lower in the spring months and higher than the corresponding temperatures of the air from July to winter. The mean annual temperature of the ground, obtained from sixteen years of observation, differed by only two-tenths of 1° from the average between the mean annual shade temperature and the mean annual open-air temperature of the air.

IX.—*Mean monthly temperatures of the water in the open air.*

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° 10.6 | ° 11.0 | ° 13.2 | ° 14.7 | ° 15.7 | ° 15.9 | ° 15.4 | ° 15.3 | ° 14.8 | ° 13.5 | ° 12.1 | ° 10.6 |

The temperature of the water in the shade follows a course similar to that of the ground, since it has a gradual ascent in the first six months of the year and a descent likewise gradual in the remaining six months. There is, however, the peculiarity that the readings for December and January are equal. The temperature of the water is kept lower than the corresponding temperatures of the air in the shade and of the ground—the greatest difference between it and the air being 3° in April, and 4° between it and the ground in December. The annual mean for the period of years which we are comparing is 13.6°, being 2° less than the annual temperature of the ground and 1.8° less than that of the air in the shade.

X.—*Synopsis of the data relative to temperature deduced from the hourly observations of sixteen years.*

| | ° C. |
|---|---|
| Annual mean under shelter | 15.4 |
| Annual mean in the open air | 15.4 |
| Annual mean of the ground at depth 0.85 meter | 15.6 |
| Annual mean of water in the shade and the open air | 13.6 |
| Absolute maximum observed in the shade | 31.6 |
| Absolute maximum observed in the open air | 49.2 |
| Absolute minimum observed under shelter | —1.7 |
| Absolute minimum observed in the open air | —7.2 |
| Maximum diurnal oscillation in the shade | 22.9 |
| Maximum diurnal oscillation in the open air | 50.7 |
| Maximum annual oscillation in the shade | 32.6 |
| Maximum annual oscillation in the open air | 56.4 |

## PART II.

*Brief summary of the other meteorological data observed in the City of Mexico during a period of sixteen years.*

Having now gone over with considerable detail the thermometric data of the climate of the City of Mexico, we will now consider the other most important meteorological elements and the extent to which they are correlated. In doing so, in order to keep this article within the limits prescribed by the Meteorological Congress, we will merely sum up the pertinent results without going into minutiæ with regard to each particular meteorological factor.

### I.—*Pressure.*

MEAN MONTHLY BAROMETRIC PRESSURE.

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 586.41 | 586.06 | 586.02 | 585.91 | 586.02 | 586.03 | 586.94 | 586.56 | 586.32 | 586.63 | 586.91 | 586.82 |

MAXIMUM PRESSURES OBSERVED IN SIXTEEN YEARS.

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 594.19 | 592.43 | 592.23 | 592.13 | 590.46 | 590.17 | 590.08 | 590.08 | 590.40 | 591.64 | 593.65 | 592.70 |

## I.—*Pressure*—Continued.

MINIMUM PRESSURES OBSERVED IN SIXTEEN YEARS.

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 580.87 | 579.80 | 580.27 | 580.18 | 580.77 | 581.41 | 581.89 | 581.41 | 581.48 | 580.40 | 581.59 | 581.47 |

| | Millimeters. |
|---|---|
| Mean annual pressure in sixteen years | 586.39 |
| Absolute maximum pressure in sixteen years | 594.19 |
| Absolute minimum pressure in sixteen years | 579.80 |
| Greatest annual oscillation of the barometer (in 1879) | 12.78 |
| Greatest diurnal oscillation of the barometer (in 1880) | 5.57 |

## II.—*Humidity and vapor tension.*

MEAN MONTHLY HUMIDITY UNDER SHELTER (IN HUNDREDTHS OF SATURATION).

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 56 | 52 | 47 | 47 | 58 | 65 | 69 | 71 | 72 | 68 | 64 | 61 |

MEAN ANNUAL TENSION OF THE AQUEOUS VAPOR (IN MILLIMETERS).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.84 | 5.82 | 6.86 | 7.03 | 8.25 | 10.02 | 9.65 | 10.48 | 10.28 | 8.91 | 7.78 | 6.81 |

| | |
|---|---|
| Mean annual humidity under shelter | 60 per cent. |
| Mean annual humidity in the open air | 62 per cent. |
| Mean annual tension of the vapor under shelter | 8.14 millimeters. |
| Mean annual tension of the vapor in the open air | 8.33 millimeters. |

## III.—*Evaporation.*

MEAN DAILY EVAPORATION UNDER SHELTER.

[Millimeters.]

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.0 | 2.6 | 3.1 | 3.6 | 3.5 | 3.1 | 2.5 | 2.3 | 1.9 | 1.9 | 1.9 | 1.8 |

MEAN DAILY EVAPORATION IN THE OPEN AIR.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5.5 | 6.5 | 8.6 | 9.1 | 8.3 | 6.8 | 6.3 | 5.9 | 5.2 | 5.3 | 5.2 | 5.5 |

| | Millimeters. |
|---|---|
| Mean daily evaporation in the shelter for the whole year | 2.5 |
| Mean daily evaporation in the open air for the whole year | 6.6 |

## IV.—*Rain.*

MONTHLY MEANS.

[Millimeters.]

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.7 | 6.4 | 12.8 | 16.7 | 40.6 | 105.4 | 105.9 | 129.8 | 107.6 | 46.6 | 12.5 | 4.5 |

## IV.—*Rain*—Continued.

### MAXIMUM QUANTITY OF RAIN IN ONE DAY.

[Millimeters.]

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19.9 | 41.4 | 27.0 | 16.8 | 37.0 | 32.7 | 62.0 | 63.5 | 40.0 | 42.8 | 28.9 | 12.0 |

| | Millimeters. |
|---|---|
| Mean annual rain | 593.5 |
| Mean quantity of rain in ten years, 1880-'90 | 614.5 |
| Greatest quantity of annual rain in sixteen years (in 1878) | 892.6 |
| Smallest quantity of annual rain in sixteen years (in 1892) | 444.2 |
| Greatest depth of rain corresponding to one day (in August, 1888) | 63.5 |

## V.—*Cloudiness.*

### MEAN MONTHLY CLOUDINESS (SCALE 0 TO 10).

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.9 | 2.6 | 3.1 | 4.0 | 5.1 | 7.0 | 7.0 | 7.4 | 7.3 | 5.9 | 4.2 | 3.4 |

### PREVAILING DIRECTION OF THE CLOUDS.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SW. | SW. | SW. | SW., W. | SW. | NE. | ENE. | NE. | NE. | NE. | SW. | SW. |

### MEAN NUMBER OF CLOUDY DAYS.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 2 | 2 | 4 | 8 | 19 | 17 | 20 | 19 | 13 | 6 | 4 |

### MEAN NUMBER OF DAYS ENTIRELY CLEAR.

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19 | 16 | 16 | 13 | 7 | 3 | 0 | 0 | 2 | 8 | 12 | 16 |

| | |
|---|---|
| Mean annual cloudiness | 5.0 |
| Prevailing direction of the cloud-motion in the year | SW. |
| Mean number of cloudy days in the year | 118 |
| Mean number of entirely clear days in the year | 112 |

## VI.—*Wind.*

### PREVAILING DIRECTION.

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NW. | NW., SE. | NE., SE. | SE. | NW., NE. | NW., NE. | NW. | NW. | NW. | NW. | NW. | NW. |

### MEAN VELOCITY OF THE WIND (IN METERS PER SECOND).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.6 | 0.7 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 1.0 | 0.6 | 0.5 |

### GREATEST VELOCITY OBSERVED (IN METERS PER SECOND).

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 18.0 | 13.8 | 11.7 | 18.5 | 16.0 | 19.3 | 18.0 | 21.0 | 16.5 | 15.2 | 12.5 | 13.5 |

VI.—*Wind*—Continued.

DIRECTION OF THE WIND OF GREATEST VELOCITY.

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NNE. | SSE. | ESE. | SSW. | SW. | NE. | NW. | NNE. | NE. | NW. | N. | S. |

Prevailing wind in the year .......... NW.
Mean annual velocity in sixteen years .......... 0.8 meters.
Maximum velocity per second in sixteen years .......... 21.0 meters.
Direction corresponding to the greatest velocity .......... NNE.

VII.—*Quantity of ozone, monthly mean, in the decimal scale.*

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° 3.2 | ° 3.7 | ° 4.4 | ° 4.8 | ° 4.9 | ° 4.7 | ° 4.7 | ° 4.5 | ° 4.2 | ° 3.6 | ° 3.4 | ....... |

Mean annual quantity of ozone .......... 4.1°

VIII.—*Description of the observatory in which the foregoing results were obtained.*

The Central Meteorological Observatory of Mexico was founded in the year 1877. It is located in the top story of the National Palace, at a height of 17.4 meters above the level of the principal plaza, and consequently at an altitude of 2,282.5 meters. Its geographical coordinates are 19° 26′ lat. N., and 6h. 36′ 31.56″ long. W. from Greenwich. In this location the mean declination of the magnetic needle is 8° 16′ E. of N.; its mean inclination is 45° 3′. The temperature of boiling water is 92.88° C. The length of a pendulum vibrating seconds of mean time is 0.99109 meter.

## PART III.

*Brief deductions from the climatic data of the City of Mexico.*

From the preceding data are deduced the following conclusions relative to the climate of the City of Mexico:

The mean monthly temperature varies from 12° C. in December to 18° C. in May. It rises from the beginning of the year to the fifth month, falls in the following one, and remains with small variation during the rainy season; it falls in the autumn and continues its descent until the winter. The course of the temperature in the open air is analogous to the preceding, and although its diurnal variations are wider, they compensate each other, giving a similar result in the annual mean.

The absolute maximum temperatures under shelter—that is to say, in the shade and freely exposed to the wind—vary from 23° C. to 31.6° C., and the corresponding limits in the open air are 37.7° and 49.2°; the first have their maxima in April and the last in September. The absolute minima under shelter ranged from —1.7° to +8.2°, and in the open air from —7.2° to +3.9°. The greatest falls of temperature have occurred

in December in both cases, and these great descents have been rare in the sixteen years compared. The greatest diurnal oscillations under shelter and in the open air have been 22.3° and 50.7°, respectively, and have taken place in the spring months. The greatest annual oscillations reached 32.6° in the shade and 56.8° in the open air. The mean annual temperatures for the air in the shade and in the open air deduced from sixteen years of observation resulted equal, namely, 15.4°, which shows that the City of Mexico has a temperate climate. The distribution of heat in the winter, as well as in the other seasons, is varied. Consequently the inconveniences caused by the extreme limits are not prolonged for many hours; in general, the temperature in winter is mild from 11 o'clock a. m. to 5 o'clock p. m., and in the other seasons the mornings and nights are always cool.

The principal elements which modify the normal course of the temperature are the winds, the clouds, and the rains. The winds from the two southern quadrants increase the heat and dry the air; the currents from the north cool and moisten it. Generally the winds from the first quadrant clear up the clouds suddenly and induce a decided lowering of the temperature. A sky entirely covered with clouds keeps the temperature high, while the passage of loose clouds at the hours of maximum temperatures impedes its rise. The hottest month is April; the coolest, December.

The course of the mean monthly temperature of the ground at the depth of 0.85 meter varied from 13.3° to 17.5°, rising from the first to the sixth month of the year and falling from June to December. The lowest reading corresponds to January and the highest to the month of June, and the regularity of its course indicates that it is free from external influences. The annual mean of 15.6° differs only two-tenths of a degree at most from the mean of the surrounding air.

The mean monthly temperature of the water under shelter varies from 10.6° to 15.9°, following an ascent and descent of six months each like that of the ground, and giving an annual mean of 13.6°, which differs by less than 2° from that of the free air.

As a consequence of the facts that have just been presented, plants of the most varied climates grow and thrive in the City of Mexico. As the falls in temperature are limited, the plants of the public gardens live and bloom in the open air at all seasons without the necessity of protection in winter. Few of the trees which grow in the streets and parks lose their leaves at the approach of winter, but in the course of this season they sprout luxuriantly and renew their foliage, so that a pleasing growth of verdure is never lacking.

The mean monthly barometric pressure varies from 585.91 mm. to 586.94 mm., these limits occurring in April and July, respectively. The minimum diurnal pressure observed was 579.80 mm. and the maximum 594.19 mm. The greatest diurnal and annual oscillations were respectively 5.57 mm. and 12.78 mm., such wide differences being rare, because

the barometric changes generally have a narrow range in Mexico. The greatest depressions occur with south winds and the barometer rises with north winds. Generally storms are announced by falling barometer and the appearance of cirrus clouds in the sky, but as the bad weather develops it is attended by the rise and perturbation of the barometer.

The mean monthly atmospheric humidity in hundredths of saturation varies from 47 to 72. It falls from January to April, and ascends with some abruptness in the following months, especially in those of summer, descending afterwards until winter. It decreases with southerly winds and rises with northerly winds. The mean annual humidity under shelter and in the open air amounts to 60 and 62 per cent respectively.

The mean monthly vapor tension under shelter varies from 5.82 mm. to 10.43 mm., which limits occur in February and August. The mean annual tension of aqueous vapor deduced from sixteen years' observations is 8.14 mm. Observations of the mean monthly quantity of water evaporated under shelter and in the open air gave the following results: Under shelter the amount varied from 1.8 mm. in December to 3.6 mm. in April, and in the open air its range was from 5.2 mm. in the winter months to 9.1 mm. in April, being increased by low barometric pressures and by southerly winds. The annual means are 2.5 mm. under shelter and 6.6 mm. in the open air.

Rain occurs generally in all months of the year, although in no regular manner in the spring. The rainy season, properly so called, can be said to begin in May, to be fully established in June, and to end in October, August being the most rainy and most stormy month. The mean quantity of water which was collected in this latter month amounted to 129.8 mm., and the greatest depth of rain corresponding to any one day in the same month amounted to 63.5. The mean annual depth of rainfall in sixteen years is found to be 593.5 mm., and the mean of the ten years from 1880–1890 is 614.5. The greatest annual depth registered in sixteen years amounted to 892.6 mm., and the minimum to 444.2. Generally, the greatest quantity of water falls on the mountains of the Valley of Mexico, whither the clouds are driven by the winds.

The cloudiness in Mexico increases in the summer months, there being in the other seasons a great number of entirely cloudless days, with a clear sky of beautiful blue. Cirrus veils are precursors of storms and last but few days. Haze on the horizon is prevalent in some of the spring months, but it disappears in the rainy season, during which the atmosphere becomes notably transparent, the twilight lasting remarkably and presenting brilliant displays at sunrise and sunset. The prevailing direction of the clouds is from the southwest, but in the rainy season they proceed from the first quadrant.

The dominant wind in the City of Mexico is the northwest, which pre-

vails the greater part of the year, especially in autumn and winter. It is the dampest and coldest wind, and the one which increases the barometric pressure. The mean annual wind velocity is 0.8 meter per second, and on studying the monthly means it is observed that in the majority of the months it is about 1 meter. The greatest velocity registered in sixteen years was 21 meters per second, in a wind blowing from the northeast. Generally in the spring there are wind squalls every afternoon, but the greatest velocities are observed in the summer just before storms. As a rule, every night, although for a few hours only, there occur gusts of north winds, which usually simply cool the air, but sometimes they cause disagreeable and even unhealthy weather.

The ozone gives mean monthly indications of 3.2° to 4.9° on the decimal scale, the annual mean being 4.1°.

The preceding data should suffice to give a general idea of the climate of the City of Mexico. They are the results of personal observations, by day and by night, conducted during the sixteen years that have elapsed since the founding of the Central Meteorologico-Magnetic Observatory. Each one of the physical elements cited might be treated in greater detail, but to do so would be to exceed the limits proposed for the present memoir. The observatory has issued numerous documents which may be referred to for many interesting details, laws, and comparative results relating to the subjects mentioned in the foregoing brief summary.

## 4.—THE CLIMATE OF THE BRITISH ISLANDS.

CHARLES HARDING.

In attempting to describe the climate of the British Islands with its peculiarities and the advance which has been made in our knowledge of the weather of recent years, I feel that with the limited space at my disposal it will not be easy, if even practicable, to do credit to the subject.

The essential characteristic of our English weather is that it is subject to constant variation within assigned limits, these limits being, so far as temperature is concerned, a degree of heat or cold which is fairly agreeable at all times, and which is seldom so extreme as to occasion any material discomfort. The discomfort, if it can be so called, consists of the sharp variations which are experienced at times and the differences which occur frequently between the temperature of successive days, although even in this respect the change is far less than is occasionally experienced in continental climates.

With respect to weather, which probably constitutes the principal factor in climate, the conditions are those of constant alternation, the settled and unsettled periods occurring in spells, for the most part, and for reasons now well understood, to which further reference will be

made subsequently, but for the present we will designate these changes cyclonic and anticyclonic.

To allow of some appreciation of the temperatures experienced in the British Islands, tables are given showing for the different districts the mean temperatures for each quarter of the year for the individual years from 1866 to 1890, and for the whole period of the quarter of a century. These values are taken from the appendixes to the "Quarterly Weather Report" published by the Meteorological Office, and afford, without doubt, the best available means for absolute comparison of temperature over the whole area of the British Islands. For the facility of identifying the warm and cold periods, the values in excess of the mean are given in italics, while those below the mean are given in ordinary type. A glance at the several tables shows that, although perhaps at first sight all may seem chaos and confusion, yet there is to a very great extent evidence of regularity. The highest and lowest means in each year are underlined, so as to enable the range in the means to be picked out. These and other individual means show the very wide difference in the seasons which exists at times, the differences often being exceptionally large, when it is considered that the results are for three months, in which time many of the irregularities are smoothed down, as it often happens that in the period there may occur both hot and cold spells, as well as wet and dry. The rainfall figures are given at the foot of each table, and in a similar manner to those of temperature. These show equal irregularities, and yet there is to a very great extent order in the seeming irregularity. The period contained in these tables is too limited to be of any real value for detecting serial changes, but as the system is still being continued by the Meteorological Office, valuable statistics are being collected which ultimately may enable the forecasting of seasons, to which it seems desirable that meteorologists should now devote special attention, in which direction no really scientific attempt has as yet been made, and the vain endeavors of the would-be weather prophet are not worthy of serious notice.

TABLE I.—*First quarter, January to March; mean temperature and rainfall for the twenty-five years 1866 to 1890.*

MEAN TEMPERATURE.

| Years. | North Scotland. | Wheat-producing districts. | | | | | Grazing districts. | | | | | British Islands generally. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | East Scotland. | Northeast England. | East England. | Midland counties. | South England. | West Scotland. | Northwest England. | Southwest England. | North Ireland. | South Ireland. | |
| | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. |
| 1866 | 38.3 | 38.8 | 39.1 | 40.9 | 40.4 | 41.9 | 40.0 | 40.6 | 43.4 | 39.9 | 40.3 | 40.5 |
| 1867 | 36.9 | 37.2 | 36.8 | 38.6 | 38.2 | 39.2 | 37.7 | 38.6 | 41.4 | 38.1 | 39.9 | 38.6 |
| 1868 | 40.7 | 41.7 | 41.1 | 41.4 | 41.9 | 42.0 | 42.3 | 42.4 | 44.4 | 42.1 | 44.3 | 42.4 |
| 1869 | 40.0 | 40.3 | 40.6 | 41.1 | 41.2 | 42.0 | 42.0 | 42.1 | 45.1 | 42.9 | 44.6 | 42.2 |
| 1870 | 37.9 | 37.4 | 37.1 | 37.4 | 38.0 | 38.2 | 38.6 | 38.7 | 41.3 | 39.8 | 41.6 | 38.8 |
| 1871 | 40.0 | 39.7 | 38.8 | 39.2 | 40.1 | 40.3 | 40.0 | 40.0 | 43.3 | 41.6 | 43.4 | 40.7 |
| 1872 | 40.9 | 40.9 | 41.3 | 42.3 | 42.9 | 43.7 | 42.9 | 43.3 | 46.1 | 42.4 | 44.5 | 43.0 |
| 1873 | 39.0 | 38.4 | 38.5 | 38.2 | 39.1 | 39.9 | 39.2 | 39.7 | 42.6 | 39.8 | 41.0 | 39.8 |
| 1874 | 41.7 | 41.8 | 41.3 | 40.4 | 41.0 | 42.0 | 42.3 | 44.8 | 45.0 | 42.8 | 45.2 | 42.4 |
| 1875 | 39.5 | 39.0 | 38.8 | 38.6 | 39.2 | 40.2 | 39.8 | 40.2 | 42.9 | 41.6 | 44.6 | 40.5 |
| 1876 | 38.7 | 38.3 | 39.2 | 39.0 | 38.9 | 40.0 | 39.5 | 39.8 | 42.4 | 40.1 | 43.3 | 40.1 |
| 1877 | 38.4 | 38.8 | 40.4 | 41.7 | 41.3 | 43.1 | 40.5 | 41.8 | 44.9 | 41.4 | 45.2 | 42.0 |
| 1878 | 39.4 | 40.1 | 40.3 | 40.6 | 41.8 | 41.7 | 41.9 | 42.2 | 44.2 | 42.5 | 45.1 | 42.1 |
| 1879 | 35.8 | 34.2 | 35.9 | 36.5 | 36.4 | 37.8 | 36.5 | 36.8 | 40.3 | 38.0 | 40.5 | 37.4 |
| 1880 | 40.6 | 39.8 | 39.5 | 39.2 | 39.9 | 40.5 | 41.3 | 40.6 | 43.5 | 42.2 | 44.1 | 41.1 |
| 1881 | 34.4 | 33.5 | 34.3 | 36.1 | 35.8 | 38.2 | 35.3 | 36.6 | 39.9 | 37.5 | 39.8 | 36.7 |
| 1882 | 41.8 | 42.9 | 42.8 | 42.1 | 42.6 | 43.5 | 43.7 | 43.5 | 44.9 | 44.8 | 46.0 | 43.7 |
| 1883 | 38.7 | 38.8 | 38.8 | 39.0 | 39.2 | 40.3 | 40.2 | 40.1 | 42.2 | 40.9 | 42.5 | 40.3 |
| 1884 | 40.7 | 41.2 | 41.9 | 42.4 | 42.6 | 43.8 | 42.4 | 42.4 | 44.5 | 42.7 | 44.8 | 42.9 |
| 1885 | 38.4 | 38.3 | 39.2 | 39.2 | 39.3 | 40.7 | 39.6 | 39.7 | 41.9 | 40.6 | 42.2 | 40.1 |
| 1886 | 36.5 | 36.1 | 36.2 | 35.6 | 36.0 | 37.2 | 37.2 | 36.9 | 38.4 | 38.6 | 40.0 | 37.2 |
| 1887 | 39.4 | 39.2 | 38.7 | 37.5 | 37.8 | 38.7 | 39.8 | 39.0 | 40.4 | 41.3 | 42.3 | 39.5 |
| 1888 | 36.2 | 36.3 | 37.3 | 36.5 | 36.8 | 37.4 | 38.1 | 37.7 | 38.5 | 39.4 | 40.5 | 37.9 |
| 1889 | 38.5 | 38.6 | 38.6 | 37.5 | 38.2 | 39.0 | 40.1 | 39.7 | 40.8 | 41.3 | 42.9 | 39.7 |
| 1890 | 40.0 | 39.8 | 40.7 | 40.1 | 40.4 | 41.6 | 41.3 | 41.2 | 42.7 | 42.0 | 43.5 | 41.3 |
| Mean for 25 years, 1866–1890 | 38.9 | 38.8 | 39.1 | 39.3 | 39.6 | 40.5 | 40.1 | 40.2 | 42.6 | 41.0 | 42.9 | 40.5 |

TABLE I.—*First quarter, January to March; mean temperature and rainfall for the twenty-five years 1866 to 1890*—Continued.

RAINFALL.

| Years. | North Scotland. | Wheat-producing districts. | | | | | Grazing districts. | | | | | British Islands generally. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | East Scotland. | Northeast England. | East England. | Midland counties. | South England. | West Scotland. | Northwest England. | Southwest England. | North Ireland. | South Ireland. | |
| | In. | In. | In. | In. | In. | In. | In. | In. | In. | In. | In. | In. |
| 1866 | 14.8 | 11.3 | 5.8 | 7.4 | 7.1 | 11.4 | 15.4 | 13.4 | 16.9 | 13.7 | 12.0 | 11.5 |
| 1867 | 10.7 | 9.5 | 5.4 | 5.7 | 8.1 | 8.8 | 9.9 | 11.1 | 15.2 | 11.8 | 10.7 | 9.6 |
| 1868 | 19.1 | 11.7 | 4.9 | 5.4 | 6.7 | 7.5 | 17.6 | 13.3 | 11.9 | 13.0 | 10.5 | 10.3 |
| 1869 | 11.8 | 8.9 | 6.2 | 6.2 | 7.7 | 9.0 | 11.4 | 12.2 | 14.0 | 12.1 | 12.1 | 10.0 |
| 1870 | 6.4 | 6.7 | 4.8 | 3.9 | 5.1 | 6.0 | 8.8 | 9.0 | 10.7 | 8.6 | 9.7 | 7.4 |
| 1871 | 9.4 | 6.9 | 3,8 | 3.9 | 4.8 | 6.1 | 11.7 | 8.7 | 10.0 | 10.7 | 9.4 | 7.6 |
| 1872 | 8.2 | 11.2 | 7.8 | 6.1 | 9.8 | 10.1 | 15.2 | 14.0 | 19.5 | 12.7 | 13.1 | 12.0 |
| 1873 | 7.9 | 7.2 | 5.3 | 5.4 | 7.1 | 8.4 | 10.0 | 9.6 | 14.1 | 8.8 | 11.9 | 8.8 |
| 1874 | 11.5 | 6.5 | 3.5 | 3.1 | 5.7 | 4.4 | 8.6 | 11.0 | 12.5 | 8.4 | 7.7 | 7.1 |
| 1875 | 8.4 | 7.0 | 3.9 | 3.7 | 5.8 | 6.7 | 9.8 | 8.7 | 12.6 | 7.1 | 10.2 | 7.6 |
| 1876 | 13.4 | 9.5 | 6.3 | 6.7 | 8.2 | 7,5 | 12.1 | 12.0 | 10.9 | 10.0 | 10.0 | 9.3 |
| 1877 | 11.9 | 9.8 | 7.1 | 7.6 | 8.3 | 10.7 | 14.2 | 15.4 | 14.2 | 13.4 | 11.4 | 11.2 |
| 1878 | 9.3 | 4.3 | 4.8 | 4.5 | 8.9 | 5.1 | 11.0 | 7.2 | 6.1 | 8.3 | 7.8 | 6.3 |
| 1879 | 5.5 | 6.9 | 5.1 | 6.2 | 6.1 | 8.2 | 8.5 | 6.7 | 11.2 | 6.7 | 11.2 | 7.7 |
| 1880 | 7.4 | 5.5 | 3.3 | 3.4 | 4.3 | 4.7 | 10.3 | 6.2 | 6.9 | 7.5 | 9.8 | 6.2 |
| 1881 | 9.2 | 7.4 | 6.3 | 5.8 | 6.4 | 6.7 | 9.5 | 8.6 | 9.7 | 7.7 | 8.7 | 7.7 |
| 1882 | 10.3 | 5.2 | 3.1 | 4.3 | 5.6 | 3.6 | 11.9 | 7.8 | 7.1 | 8.3 | 9.7 | 6.7 |
| 1883 | 8.9 | 6.5 | 5.8 | 6.4 | 7.4 | 7.5 | 12.2 | 8.5 | 10.4 | 10.2 | 13.8 | 8.9 |
| 1884 | 12.1 | 6.4 | 6.2 | 3.9 | 6.7 | 6.7 | 17.1 | 11.5 | 12.3 | 12.2 | 15.4 | 9.9 |
| 1885 | 9.1 | 5.4 | 4.4 | 5.3 | 6.1 | 7.3 | 11.9 | 7.7 | 9.1 | 8.4 | 11.8 | 7.8 |
| 1886 | 9.5 | 5.9 | 6.3 | 4.9 | 6.5 | 6.3 | 11.2 | 9.0 | 10.8 | 10.0 | 11.2 | 8.2 |
| 1887 | 12.1 | 5.3 | 3.8 | 3.8 | 4.1 | 4.1 | 9.7 | 5.9 | 5.5 | 7.3 | 7.6 | 5.7 |
| 1888 | 10.2 | 6.9 | 5.6 | 5.1 | 4.6 | 5.8 | 8.6 | 5.0 | 7.1 | 7.2 | 7.6 | 6.4 |
| 1889 | 13.8 | 4.8 | 4.8 | 3.9 | 5.6 | 5.1 | 10.6 | 6.0 | 9.1 | 8.6 | 8.6 | 6.7 |
| 1890 | 15.2 | 8.1 | 5.3 | 5.6 | 5.1 | 5.6 | 13.6 | 8.4 | 8.9 | 8.7 | 12.7 | 8.2 |
| Mean for 25 years, 1866-1890 | 10.6 | 7.4 | 5.2 | 5.1 | 6.3 | 6.9 | 11.6 | 9.5 | 11.1 | 9.7 | 10.6 | 8.4 |

Table I gives the results for the first quarter of the year, January to March. It shows that for the British Islands generally the mean temperature was highest in 1882, when the average was 43.7° F., and strangely the first quarter of the year was coldest in 1881, when the average was 36.7°, so that the extremes during the quarter of the century were in consecutive years. The warmest districts during the first quarter of the year are the south of Ireland and the southwest of England, where the means are respectively 42.9° and 42.6°. The lowest mean is 38.8°, in the east of Scotland. In the first thirteen years there were only four first quarters which were cold, while in the last twelve years there were only four first quarters which were warm. The rainfall results show that for the whole of the British Islands the wettest first quarter was 1872, when the average fall was 12 inches.

The driest was 1880, with a total fall of 6.2 inches. In the first twelve years, 1866 to 1877, there were only four first quarters with a rainfall below the average, while in the last thirteen years, 1878 to 1890, there were only two first quarters, 1883 and 1884, with an excess of rainfall. The average temperature for the whole of the British Islands for the first three months of the year is 40.5°, and the average rainfall is 8.4 inches.

TABLE II.—*Second quarter, April to June; mean temperature and rainfall for the twenty-five years 1866 to 1890.*

MEAN TEMPERATURE.

| Years. | North Scotland. | Wheat-producing districts. | | | | | Grazing districts. | | | | | British Islands generally. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | East Scotland. | Northeast England. | East England. | Midland counties. | South England. | West Scotland. | Northwest England. | Southwest England. | North Ireland. | South Ireland. | |
| | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. |
| 1866 | 48.2 | 48.1 | 48.0 | 52.2 | 51.7 | 52.9 | 50.9 | 50.6 | 53.0 | 51.9 | 51.4 | 51.1 |
| 1867 | 47.2 | 49.9 | 48.5 | 52.7 | 52.2 | 52.8 | 51.1 | 51.6 | 53.6 | 53.1 | 52.9 | 51.9 |
| 1868 | 49.7 | 52.3 | 52.1 | 55.1 | 55.7 | 54.8 | 52.3 | 53.5 | 55.0 | 52.8 | 54.6 | 53.8 |
| 1869 | 47.7 | 49.4 | 49.2 | 50.9 | 51.6 | 51.7 | 50.1 | 50.3 | 53.5 | 51.3 | 52.6 | 51.1 |
| 1870 | 49.5 | 52.5 | 51.4 | 52.8 | 54.4 | 53.5 | 51.9 | 52.8 | 54.3 | 53.2 | 53.5 | 53.0 |
| 1871 | 47.2 | 48.4 | 47.9 | 49.5 | 51.7 | 51.2 | 50.8 | 50.7 | 53.7 | 52.4 | 53.9 | 51.0 |
| 1872 | 48.2 | 49.7 | 49.7 | 52.0 | 51.8 | 51.9 | 50.3 | 51.0 | 51.9 | 50.5 | 51.6 | 51.0 |
| 1873 | 47.9 | 49.8 | 49.1 | 49.8 | 51.6 | 51.7 | 51.7 | 51.3 | 52.5 | 51.9 | 53.2 | 51.3 |
| 1874 | 48.4 | 49.6 | 49.9 | 51.3 | 52.4 | 52.7 | 51.1 | 51.4 | 54.0 | 51.5 | 54.3 | 51.9 |
| 1875 | 49.3 | 51.4 | 51.2 | 52.4 | 52.8 | 52.9 | 51.7 | 52.0 | 53.1 | 51.9 | 53.3 | 52.3 |
| 1876 | 48.2 | 49.7 | 49.8 | 51.1 | 51.8 | 51.3 | 50.3 | 50.5 | 52.1 | 49.8 | 52.2 | 50.8 |
| 1877 | 46.6 | 47.5 | 48.4 | 50.8 | 51.1 | 51.8 | 49.1 | 49.5 | 52.3 | 49.3 | 52.2 | 50.2 |
| 1878 | 48.8 | 50.6 | 51.7 | 53.8 | 54.3 | 54.8 | 52.5 | 53.5 | 53.5 | 52.6 | 53.7 | 53.1 |
| 1879 | 45.0 | 46.8 | 47.5 | 48.8 | 49.0 | 49.8 | 48.4 | 48.6 | 50.0 | 48.4 | 50.0 | 48.8 |
| 1880 | 47.6 | 49.9 | 49.5 | 51.1 | 50.9 | 52.0 | 50.5 | 50.5 | 52.8 | 50.4 | 52.1 | 51.0 |
| 1881 | 46.8 | 50.1 | 50.6 | 52.6 | 52.9 | 53.5 | 50.8 | 51.8 | 52.5 | 51.8 | 52.8 | 51.9 |
| 1882 | 47.5 | 49.4 | 50.4 | 52.4 | 52.2 | 53.8 | 50.7 | 51.8 | 52.4 | 51.2 | 52.2 | 51.7 |
| 1883 | 47.3 | 50.1 | 50.2 | 52.1 | 52.2 | 52.9 | 50.0 | 51.0 | 51.7 | 50.5 | 51.5 | 51.2 |
| 1884 | 46.8 | 49.4 | 50.0 | 51.2 | 51.4 | 52.4 | 50.1 | 50.6 | 51.5 | 50.6 | 51.8 | 50.9 |
| 1885 | 45.8 | 48.6 | 49.0 | 50.5 | 50.2 | 51.8 | 48.3 | 49.0 | 50.0 | 48.7 | 49.6 | 49.6 |
| 1886 | 45.6 | 47.8 | 47.9 | 50.5 | 50.5 | 52.0 | 48.1 | 49.4 | 51.2 | 48.9 | 50.8 | 49.7 |
| 1887 | 48.4 | 50.5 | 50.3 | 51.4 | 52.0 | 52.4 | 51.0 | 51.2 | 52.6 | 52.2 | 53.3 | 51.7 |
| 1888 | 46.5 | 47.6 | 48.4 | 50.5 | 50.5 | 51.1 | 49.4 | 49.9 | 50.8 | 50.0 | 51.8 | 50.0 |
| 1889 | 49.7 | 50.9 | 51.3 | 53.1 | 53.4 | 54.7 | 51.9 | 52.6 | 53.0 | 51.7 | 52.4 | 52.5 |
| 1890 | 48.0 | 49.2 | 49.8 | 51.4 | 51.2 | 52.6 | 50.2 | 51.0 | 52.0 | 50.9 | 52.1 | 51.0 |
| Mean for 25 years, 1866–1890 | 47.7 | 49.6 | 49.7 | 51.6 | 51.9 | 52.5 | 50.5 | 51.0 | 52.5 | 51.1 | 52.4 | 51.3 |

TABLE II.—*Second quarter, April to June; mean temperature and rainfall for the twenty-five years 1866 to 1890*—Continued.

RAINFALL.

| Years. | North Scotland. | Wheat-producing districts. | | | | | Grazing districts. | | | | | British Islands generally. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | East Scotland. | Northeast England. | East England. | Midland counties. | South England. | West Scotland. | Northwest England. | Southwest England. | North Ireland. | South Ireland. | |
| | In. | In. | In. | In. | In. | In. | In. | In. | In. | In. | In. | In. |
| 1866 | 6.2 | 4.8 | 5.2 | 6.0 | 6.8 | 6.7 | 5.1 | 6.8 | 6.5 | 6.7 | 8.2 | 6.2 |
| 1867 | 10.6 | 8.0 | 6.8 | 6.2 | 6.7 | 5.8 | 10.5 | 8.3 | 10.0 | 10.0 | 9.3 | 8.2 |
| 1868 | 10.9 | 6.1 | 3.7 | 3.2 | 3.8 | 4.1 | 7.7 | 4.4 | 5.9 | 6.6 | 6.8 | 5.2 |
| 1869 | 6.7 | 5.8 | 7.5 | 5.0 | 7.5 | 6.6 | 4.8 | 7.6 | 8.2 | 7.7 | 7.8 | 6.8 |
| 1870 | 9.5 | 4.1 | 4.8 | 2.8 | 2.5 | 2.4 | 7.4 | 5.7 | 4.2 | 6.4 | 4.6 | 4.4 |
| 1871 | 4.8 | 6.1 | 7.5 | 7.5 | 7.5 | 7.7 | 8.3 | 7.7 | 8.4 | 7.5 | 7.7 | 7.6 |
| 1872 | 11.4 | 10.4 | 7.4 | 6.6 | 8.6 | 8.5 | 11.3 | 12.0 | 10.9 | 9.8 | 7.6 | 9.3 |
| 1873 | 7.9 | 5.9 | 4.8 | 4.7 | 5.6 | 4.3 | 5.1 | 4.7 | 5.9 | 6.3 | 5.1 | 5.3 |
| 1874 | 10.0 | 4.5 | 3.4 | 3.9 | 3.9 | 5.3 | 5.5 | 5.0 | 4.5 | 6.8 | 4.2 | 4.7 |
| 1875 | 8.7 | 5.5 | 4.2 | 4.9 | 6.4 | 6.0 | 6.5 | 7.6 | 9.8 | 7.0 | 6.5 | 6.4 |
| 1876 | 8.4 | 6.1 | 6.2 | 4.9 | 5.5 | 4.9 | 6.4 | 7.0 | 5.5 | 5.6 | 5.0 | 5.7 |
| 1877 | 10.1 | 8.8 | 6.7 | 5.6 | 6.8 | 6.2 | 9.5 | 8.4 | 11.2 | 8.5 | 10.9 | 8.3 |
| 1878 | 3.7 | 6.2 | 7.6 | 8.2 | 9.2 | 8.4 | 8.7 | 8.3 | 11.6 | 9.1 | 13.9 | 9.1 |
| 1879 | 4.5 | 8.3 | 8.3 | 10.1 | 10.0 | 10.3 | 9.9 | 8.4 | 11.3 | 10.0 | 11.6 | 9.8 |
| 1880 | 4.9 | 4.9 | 6.6 | 7.2 | 7.2 | 5.5 | 8.0 | 6.7 | 5.4 | 8.5 | 7.8 | 6.7 |
| 1881 | 7.0 | 5.6 | 4.5 | 4.3 | 4.3 | 4.2 | 9.3 | 8.6 | 6.1 | 8.5 | 8.3 | 6.4 |
| 1882 | 7.4 | 7.4 | 9.2 | 8.0 | 9.9 | 7.9 | 10.5 | 10.6 | 10.2 | 9.4 | 10.3 | 9.3 |
| 1883 | 5.7 | 3.8 | 6.0 | 6.7 | 7.2 | 5.1 | 7.8 | 5.9 | 6.1 | 6.2 | 7.6 | 6.2 |
| 1884 | 6.4 | 3.6 | 3.2 | 3.8 | 4.2 | 4.7 | 5.4 | 3.8 | 4.9 | 5.8 | 4.6 | 4.4 |
| 1885 | 6.8 | 5.5 | 6.1 | 6.5 | 6.8 | 6.0 | 7.3 | 6.0 | 8.7 | 6.1 | 7.8 | 6.7 |
| 1886 | 6.7 | 6.4 | 6.1 | 5.2 | 9.4 | 6.4 | 8.8 | 9.4 | 7.3 | 7.9 | 8.2 | 7.5 |
| 1887 | 6.2 | 3.7 | 3.0 | 3.6 | 4.0 | 3.8 | 5.8 | 3.8 | 3.5 | 4.5 | 3.3 | 3.9 |
| 1888 | 8.5 | 7.1 | 5.1 | 5.1 | 6.0 | 6.2 | 11.4 | 6.4 | 7.5 | 9.8 | 10.1 | 7.5 |
| 1889 | 4.9 | 5.8 | 5.0 | 7.3 | 8.1 | 5.7 | 7.7 | 6.8 | 5.9 | 7.2 | 7.6 | 6.7 |
| 1890 | 8.5 | 5.6 | 4.7 | 4.5 | 4.7 | 6.3 | 10.1 | 6.0 | 8.1 | 6.8 | 8.5 | 6.5 |
| Mean for 25 years, 1866–1890 | 7.4 | 6.0 | 5.7 | 5.7 | 6.5 | 6.0 | 7.9 | 7.0 | 7.5 | 7.5 | 7.7 | 6.8 |

Table II gives the results for the second quarter of the year, April to June. It shows that for the British Islands generally the warmest second quarter occurred in 1868, when the mean temperature was 53.8°, while the coldest was 48.8° in 1879. The warmest districts were the south and southwest of England and the south of Ireland, where the mean was about 52.5°, while in the north of Scotland the mean for the three months for the twenty-five years was only 47.7°. The rainfall results show that the wettest second quarter was 9.8 inches in 1879, and the driest, 3.9 inches in 1887. There were fifteen years with the rainfall below the average during the second quarter, and only ten with an excess. The average temperature for the whole of the British Islands for the second quarter is 51.3°, and the average rainfall is 6.8 inches, which shows an increase of 10.8° of temperature in the course of the three months, and a decrease of rainfall of 1.6 inches for the period.

**TABLE III.**—*Third quarter, July to September; mean temperature and rainfall for the twenty-five years 1866 to 1890.*

MEAN TEMPERATURE.

| Years. | North Scotland. | Wheat-producing districts. | | | | | Grazing districts. | | | | | British Islands generally. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | East Scotland. | Northeast England. | East England. | Midland counties. | South England. | West Scotland. | Northwest England. | Southwest England. | North Ireland. | South Ireland. | |
| | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. |
| 1866 | 53.2 | 55.4 | 55.4 | 57.6 | 56.8 | 58.1 | 56.2 | 56.8 | 58.4 | 56.0 | 57.2 | 56.8 |
| 1867 | 53.7 | 56.0 | 55.9 | 58.8 | 58.5 | 59.2 | 57.2 | 58.2 | 60.0 | 58.5 | 59.4 | 58.2 |
| 1868 | 55.0 | 58.5 | 58.8 | 62.5 | 62.4 | 62.4 | 59.5 | 61.2 | 63.6 | 59.1 | 60.8 | 60.9 |
| 1869 | 54.4 | 57.4 | 57.6 | 60.2 | 60.5 | 60.3 | 58.2 | 59.1 | 61.4 | 59.5 | 59.8 | 59.4 |
| 1870 | 55.6 | 58.1 | 57.2 | 59.6 | 60.5 | 60.3 | 58.5 | 59.5 | 61.7 | 59.6 | 60.3 | 59.5 |
| 1871 | 55.1 | 57.4 | 57.5 | 59.9 | 59.5 | 60.1 | 57.3 | 58.3 | 60.6 | 57.2 | 58.0 | 58.6 |
| 1872 | 54.0 | 55.9 | 57.1 | 59.7 | 60.1 | 60.3 | 57.7 | 59.1 | 60.7 | 57.9 | 59.3 | 58.8 |
| 1873 | 54.1 | 56.4 | 57.3 | 59.1 | 56.7 | 59.4 | 57.4 | 57.8 | 59.5 | 56.6 | 57.9 | 58.0 |
| 1874 | 54.4 | 56.7 | 57.9 | 60.2 | 60.3 | 60.2 | 57.8 | 58.8 | 60.6 | 56.9 | 59.0 | 58.9 |
| 1875 | 54.8 | 57.0 | 57.8 | 59.7 | 59.6 | 60.2 | 58.4 | 58.7 | 60.6 | 57.5 | 60.0 | 59.0 |
| 1876 | 54.3 | 56.3 | 57.7 | 60.4 | 60.7 | 61.1 | 57.6 | 58.8 | 61.0 | 56.6 | 59.4 | 59.0 |
| 1877 | 52.7 | 55.0 | 55.5 | 57.9 | 57.7 | 58.2 | 55.3 | 56.0 | 58.3 | 55.1 | 57.3 | 56.7 |
| 1878 | 55.2 | 58.5 | 59.1 | 60.4 | 60.2 | 61.6 | 59.2 | 59.5 | 61.3 | 58.8 | 60.7 | 60.0 |
| 1879 | 52.4 | 54.2 | 56.2 | 58.1 | 57.8 | 58.7 | 55.2 | 56.2 | 57.5 | 54.8 | 57.5 | 56.6 |
| 1880 | 55.9 | 57.8 | 59.5 | 61.1 | 60.1 | 62.1 | 58.6 | 59.8 | 61.3 | 58.8 | 60.1 | 59.9 |
| 1881 | 52.1 | 56.8 | 56.8 | 58.6 | 57.7 | 59.4 | 54.8 | 56.4 | 57.5 | 55.8 | 56.4 | 57.1 |
| 1882 | 54.2 | 56.6 | 57.7 | 58.2 | 57.1 | 58.8 | 56.0 | 56.8 | 57.4 | 55.9 | 56.2 | 57.1 |
| 1883 | 52.9 | 55.8 | 56.9 | 58.5 | 57.7 | 59.5 | 55.9 | 57.2 | 57.5 | 55.8 | 56.9 | 57.2 |
| 1884 | 54.5 | 57.5 | 59.1 | 61.8 | 60.7 | 62.4 | 58.2 | 59.6 | 60.5 | 57.9 | 59.0 | 59.7 |
| 1885 | 51.7 | 55.0 | 56.2 | 58.0 | 57.7 | 59.6 | 54.8 | 56.2 | 57.7 | 55.7 | 57.3 | 56.8 |
| 1886 | 52.4 | 56.1 | 58.1 | 60.2 | 59.7 | 61.3 | 55.8 | 57.7 | 59.4 | 56.5 | 58.2 | 58.3 |
| 1887 | 52.9 | 55.8 | 57.1 | 59.1 | 58.2 | 59.7 | 55.6 | 57.5 | 58.7 | 56.5 | 58.4 | 57.7 |
| 1888 | 51.7 | 53.2 | 54.4 | 57.1 | 55.8 | 58.0 | 54.2 | 55.4 | 56.7 | 55.0 | 56.2 | 55.6 |
| 1889 | 53.2 | 54.7 | 56.4 | 58.1 | 57.5 | 59.4 | 55.5 | 56.9 | 58.0 | 56.1 | 57.5 | 57.0 |
| 1890 | 53.8 | 55.7 | 57.7 | 58.8 | 58.1 | 59.8 | 56.1 | 57.5 | 58.1 | 56.5 | 57.6 | 57.6 |
| Mean for 25 years, 1866-1890 | 53.8 | 56.2 | 57.2 | 59.3 | 58.9 | 60.0 | 56.8 | 58.0 | 59.5 | 57.0 | 58.4 | 58.1 |

TABLE III.—*Third quarter, July to September; mean temperature and rainfall for the twenty-five years 1866 to 1890*—Continued.

RAINFALL.

| Years. | North Scotland. | Wheat-producing districts. | | | | | Grazing districts. | | | | | British Islands generally. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | East Scotland. | Northeast England. | East England. | Midland counties. | South England. | West Scotland. | Northwest England. | Southwest England. | North Ireland. | South Ireland. | |
| | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* |
| 1866 | 11.8 | 10.6 | 9.3 | 7.9 | 11.7 | 9.7 | 15.1 | 16.1 | 15.2 | 12.0 | 8.9 | 11.7 |
| 1867 | 10.0 | 10.1 | 7.1 | 7.1 | 7.4 | 8.6 | 12.9 | 10.4 | 8.7 | 11.8 | 8.8 | 9.3 |
| 1868 | 9.7 | 10.4 | 6.0 | 4.2 | 7.1 | 7.2 | 9.1 | 6.7 | 9.5 | 8.1 | 11.0 | 8.0 |
| 1869 | 12.8 | 7.9 | 5.8 | 5.6 | 6.4 | 6.0 | 10.4 | 11.5 | 9.9 | 9.4 | 8.5 | 8.1 |
| 1870 | 8.6 | 5.8 | 3.5 | 5.8 | 4.5 | 4.8 | 6.8 | 5.0 | 7.0 | 7.6 | 5.7 | 5.7 |
| 1871 | 13.0 | 8.7 | 9.7 | 7.5 | 10.8 | 10.3 | 9.8 | 11.8 | 14.2 | 11.1 | 10.5 | 10.5 |
| 1872 | 12.1 | 12.5 | 10.4 | 9.8 | 9.4 | 6.6 | 16.1 | 15.8 | 13.1 | 14.7 | 11.2 | 12.0 |
| 1873 | 13.7 | 11.8 | 7.2 | 6.4 | 6.8 | 7.3 | 15.7 | 11.8 | 14.0 | 14.2 | 11.8 | 10.7 |
| 1874 | 15.5 | 11.6 | 5.8 | 5.1 | 7.1 | 6.3 | 13.4 | 12.6 | 13.8 | 11.8 | 10.1 | 9.8 |
| 1875 | 11.2 | 8.9 | 9.1 | 8.6 | 11.5 | 9.4 | 11.2 | 12.7 | 15.3 | 9.2 | 10.6 | 10.7 |
| 1876 | 8.9 | 7.4 | 8.0 | 8.1 | 9.0 | 7.9 | 10.3 | 11.2 | 13.8 | 10.0 | 9.6 | 9.6 |
| 1877 | 10.8 | 11.3 | 10.1 | 8.1 | 10.4 | 7.6 | 12.6 | 15.4 | 14.5 | 12.0 | 10.4 | 11.3 |
| 1878 | 8.0 | 8.0 | 8.4 | 6.9 | 9.1 | 7.5 | 10.5 | 10.8 | 9.2 | 8.1 | 10.5 | 8.9 |
| 1879 | 9.8 | 9.9 | 9.0 | 12.1 | 10.8 | 11.2 | 15.8 | 13.9 | 12.9 | 15.8 | 12.4 | 12.4 |
| 1880 | 7.5 | 7.7 | 10.5 | 10.0 | 11.2 | 9.4 | 9.4 | 10.0 | 7.7 | 9.8 | 10.8 | 9.7 |
| 1881 | 6.5 | 9.1 | 10.3 | 8.5 | 8.3 | 8.2 | 10.4 | 11.0 | 9.4 | 8.6 | 10.3 | 9.4 |
| 1882 | 8.2 | 8.0 | 6.9 | 7.0 | 8.1 | 7.2 | 12.3 | 11.5 | 13.2 | 11.5 | 11.1 | 9.7 |
| 1883 | 8.5 | 10.1 | 8.3 | 8.1 | 8.9 | 6.7 | 12.2 | 9.8 | 10.1 | 11.4 | 12.8 | 9.9 |
| 1884 | 7.8 | 6.3 | 5.3 | 7.4 | 6.2 | 5.9 | 12.3 | 9.0 | 8.6 | 10.2 | 7.1 | 7.8 |
| 1885 | 8.1 | 6.0 | 5.7 | 6.2 | 5.9 | 5.1 | 11.6 | 7.8 | 8.8 | 9.9 | 9.9 | 7.7 |
| 1886 | 8.7 | 5.0 | 6.8 | 6.5 | 6.4 | 5.8 | 11.4 | 10.3 | 9.3 | 9.3 | 10.9 | 8.2 |
| 1887 | 10.3 | 7.6 | 6.1 | 5.4 | 5.2 | 5.8 | 10.8 | 7.1 | 7.3 | 10.5 | 7.9 | 7.4 |
| 1888 | 9.3 | 7.1 | 9.2 | 8.4 | 7.9 | 7.9 | 10.6 | 10.5 | 11.0 | 10.3 | 9.3 | 9.2 |
| 1889 | 11.0 | 8.8 | 7.7 | 9.1 | 7.8 | 6.6 | 10.8 | 10.2 | 9.1 | 11.9 | 9.8 | 9.3 |
| 1890 | 12.1 | 8.4 | 8.3 | 7.2 | 6.6 | 8.6 | 12.0 | 9.2 | 9.8 | 10.2 | 8.4 | 8.9 |
| Mean for 25 years, 1866–1890 | 10.2 | 8.7 | 7.8 | 7.5 | 8.2 | 7.5 | 11.7 | 10.8 | 11.0 | 10.7 | 9.9 | 9.4 |

Table III gives the results for the third quarter of the year, July to September. It shows that for the British Islands generally the warmest third quarter occurred in 1868, when the mean was 60.9°, while the coldest was 55.6° in 1888. In the first ten years, from 1866 to 1875, there were only two third quarters with a deficiency of temperature, and in the first fifteen years there were only four first quarters with a deficiency, while in the last ten years, 1881 to 1890, there were only two third quarters with an excess of temperature. The warmest district was the southwest of England, where the mean was 60°; the coldest was 53.8°, in the north of Scotland, the difference being larger than in any other quarter of the year. The rainfall results show that the wettest third quarter was 1879, when the total fall was 12.4 inches for the whole of the British Islands; the driest was 5.7 inches in 1870. In the first eighteen years, 1866 to 1883, there were only five third quarters

**with a deficiency of rainfall, and of these four were from 1867 to 1870, while each of the seven years 1884 to 1890 had a rainfall less than the average. The average temperature for the whole of the British Islands for the third quarter is 58.1°, and the average rainfall is 9.4 inches, which shows an increase of 6.8° of temperature in the course of the three months, and an increase of 2.6 inches of rain for the period.**

TABLE IV.—*Fourth quarter, October to December; mean temperature and rainfall for the twenty-five years 1866 to 1890.*

MEAN TEMPERATURE.

| Years. | North Scotland. | Wheat-producing districts. | | | | | Grazing districts. | | | | | British Islands generally. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | East Scotland. | Northeast England. | East England. | Midland counties. | South England. | West Scotland. | Northwest England. | Southwest England. | North Ireland. | South Ireland. | |
| | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* |
| 1866 | *43.6* | *44.2* | *45.1* | *46.1* | *45.7* | *46.8* | *46.0* | *46.2* | *50.3* | *45.4* | *46.9* | *46.3* |
| 1867 | *43.9* | *42.9* | 42.3 | *43.0* | 42.6 | 43.2 | *43.4* | 42.9 | 45.8 | *44.2* | 44.9 | 43.5 |
| 1868 | 42.0 | *42.0* | *43.1* | *44.8* | *44.3* | *45.5* | *43.6* | *44.2* | *48.1* | *44.0* | *45.5* | 44.5 |
| 1869 | 40.9 | 41.5 | 41.8 | 42.7 | *42.9* | 43.7 | 42.5 | *43.9* | *46.6* | *44.7* | *45.5* | 43.6 |
| 1870 | 40.3 | 40.0 | 40.3 | 41.6 | 41.3 | 41.9 | 40.5 | 41.6 | 44.4 | 41.5 | 43.2 | 41.6 |
| 1871 | *42.2* | *42.1* | 42.3 | 41.5 | 41.7 | 41.8 | 42.4 | 43.0 | 45.3 | 43.2 | 44.7 | 42.8 |
| 1872 | *42.4* | *42.0* | *43.3* | *44.4* | *44.2* | *45.4* | *43.6* | *44.4* | *47.3* | 42.8 | 44.1 | *44.2* |
| 1873 | *43.4* | *42.9* | *44.2* | *43.9* | *43.6* | *44.5* | *44.2* | *44.7* | *46.9* | *44.3* | *46.3* | *44.6* |
| 1874 | 41.4 | 39.9 | 40,8 | 41.8 | 41.7 | 43.0 | 40.5 | 42.3 | 46.0 | 42.8 | *45.7* | 42.5 |
| 1875 | *42.7* | *42.1* | *43.0* | 42.7 | *43.0* | 43.5 | 42.8 | 43.6 | 45.9 | 43.5 | *46.0* | *43.7* |
| 1876 | *44.0* | *43.4* | *45.2* | *46.2* | *44.8* | *47.2* | *44.6* | *46.1* | *49.0* | *45.7* | *48.1* | *46.1* |
| 1877 | *42.9* | *43.3* | *43.6* | *44.4* | *44.1* | *44.8* | *44.5* | *45.3* | *49.2* | *44.4* | *47.4* | *45.1* |
| 1878 | 40.5 | 39.7 | 39.8 | 40.8 | 40.7 | 42.3 | 40.9 | 41.5 | 44.5 | 42.1 | 42.8 | 41.6 |
| 1879 | 41.8 | 41.0 | 40.3 | 39.7 | 39.8 | 41.2 | 42.2 | 42.0 | 45.3 | 43.0 | 45.0 | 42.0 |
| 1880 | 39.1 | 40.4 | 42.4 | *43.6* | *42.7* | *45.3* | 42.2 | 43.6 | *47.7* | 42.9 | 44.9 | 43.6 |
| 1881 | *43.2* | *43.0* | *43.2* | *43.5* | *45.2* | *45.2* | *44.3* | *44.5* | *47.7* | *44.3* | *46.8* | *44.6* |
| 1882 | 41.3 | 40.1 | *43.6* | *43.5* | *43.8* | *45.5* | 42.2 | *44.0* | *46.5* | 42.8 | 44.6 | 43.5 |
| 1883 | *42.4* | *43.0* | *43.8* | *44.2* | *43.8* | *45.6* | *44.3* | *45.0* | *46.9* | *44.6* | *46.5* | *44.8* |
| 1884 | *44.4* | *43.6* | *43.8* | *43.6* | *43.3* | *45.3* | *43.8* | *44.4* | 46.2 | *44.1* | 45.1 | *44.2* |
| 1885 | 41.5 | 41.5 | 42.6 | 42.3 | 41.9 | 44.0 | 42.9 | 42.7 | 45.0 | 43.7 | 45.1 | 43.2 |
| 1886 | *42.6* | *42.5* | *43.6* | *43.9* | *43.5* | *45.6* | *44.4* | *44.7* | 46.3 | *44.2* | *45.8* | *44.5* |
| 1887 | 39.2 | 39.4 | 40.3 | 40.2 | 39.9 | 41.7 | 40.7 | 41.3 | 42.7 | 41.8 | 42.8 | 41.1 |
| 1888 | *43.2* | *43.4* | *44.1* | *43.9* | *43.8* | *46.1* | *45.1* | *45.3* | *47.1* | *45.5* | *47.0* | *45.2* |
| 1889 | *43.1* | *42.2* | *43.1* | *43.0* | *42.7* | *44.9* | *44.4* | *44.1* | 45.8 | *45.0* | *46.2* | *44.2* |
| 1890 | *42.3* | 41.5 | 42.1 | 40.5 | 40.4 | 42.2 | *43.3* | 42.6 | 44.0 | *44.3* | *45.6* | 42.7 |
| Mean for 25 years, 1866–1890 | 42.2 | 41.9 | 42.7 | 43.0 | 42.7 | 44.2 | 43.2 | 43.8 | 46.4 | 43.8 | 45.5 | 43.7 |

TABLE IV.—*Fourth quarter, October to December; mean temperature and rainfall for the twenty-five years 1866 to 1890*—Continued.

RAINFALL.

| Years. | North Scotland. | Wheat-producing districts. | | | | | Grazing districts. | | | | | British Islands generally. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | East Scotland. | Northeast England. | East England. | Midland counties. | South England. | West Scotland. | Northwest England. | Southwest England. | North Ireland. | South Ireland. | |
| | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* |
| 1866 | 20.6 | 9.0 | 6.0 | 5.9 | 6.7 | 6.3 | 14.4 | 15.3 | 12.4 | 11.9 | 9.2 | 9.7 |
| 1867 | 16.8 | 5.7 | 4.8 | 5.7 | 5.5 | 6.8 | 10.4 | 10.3 | 12.1 | 9.6 | 7.5 | 9.8 |
| 1868 | 19.0 | 10.3 | 9.5 | 7.9 | 9.7 | 11.4 | 15.1 | 18.5 | 18.3 | 14.0 | 14.3 | 12.9 |
| 1869 | 19.8 | 9.8 | 7.9 | 9.1 | 7.7 | 8.5 | 14.0 | 13.6 | 14.3 | 13.1 | 9.5 | 10.8 |
| 1870 | 16.0 | 9.3 | 10.5 | 8.4 | 8.6 | 9.5 | 10.6 | 16.0 | 15.9 | 14.6 | 12.2 | 11.6 |
| 1871 | 15.1 | 7.3 | 5.4 | 4.3 | 4.2 | 4.6 | 10.7 | 10.7 | 12.4 | 7.6 | 9.4 | 7.7 |
| 1872 | 18.0 | 15.0 | 11.6 | 10.6 | 12.0 | 16.5 | 16.3 | 17.4 | 25.1 | 16.8 | 17.6 | 15.9 |
| 1873 | 21.2 | 9.6 | 3.5 | 4.6 | 4.6 | 6.5 | 11.7 | 10.6 | 9.4 | 7.9 | 7.9 | 7.7 |
| 1874 | 17.8 | 9.2 | 8.0 | 7.0 | 7.4 | 10.6 | 14.4 | 15.0 | 16.0 | 12.0 | 12.7 | 11.3 |
| 1875 | 13.7 | 11.1 | 10.1 | 9.6 | 11.4 | 11.2 | 12.5 | 12.7 | 18.5 | 10.1 | 13.1 | 12.1 |
| 1876 | 13.7 | 13.2 | 10.5 | 7.5 | 11.7 | 13.4 | 16.0 | 14.1 | 19.1 | 14.4 | 17.6 | 13.8 |
| 1877 | 23.1 | 11.3 | 6.4 | 6.4 | 7.4 | 10.6 | 18.1 | 17.8 | 17.2 | 14.3 | 14.0 | 12.4 |
| 1878 | 11.1 | 8.1 | 10.4 | 9.6 | 7.8 | 8.3 | 11.0 | 9.1 | 13.3 | 11.7 | 8.1 | 9.7 |
| 1879 | 8.6 | 4.8 | 3.6 | 3.8 | 2.8 | 2.5 | 6.5 | 5.2 | 4.3 | 4.9 | 4.2 | 4.2 |
| 1880 | 12.6 | 8.2 | 9.8 | 9.4 | 11.0 | 12.9 | 12.2 | 13.6 | 16.4 | 9.6 | 12.4 | 11.6 |
| 1881 | 11.2 | 7.2 | 7.2 | 8.5 | 8.6 | 9.5 | 15.8 | 11.9 | 14.2 | 12.1 | 13.4 | 10.9 |
| 1882 | 11.9 | 11.4 | 11.2 | 11.7 | 13.0 | 12.6 | 16.9 | 13.2 | 19.8 | 12.5 | 14.8 | 13.7 |
| 1883 | 14.8 | 5.8 | 5.8 | 7.6 | 7.4 | 7.2 | 18.4 | 11.3 | 11.8 | 12.2 | 11.1 | 9.9 |
| 1884 | 14.6 | 6.9 | 5.1 | 6.9 | 5.3 | 6.0 | 16.1 | 8.7 | 10.2 | 13.2 | 9.8 | 8.8 |
| 1885 | 11.0 | 4.6 | 7.0 | 9.2 | 8.6 | 9.0 | 11.8 | 9.8 | 12.7 | 8.9 | 10.1 | 9.2 |
| 1886 | 14.3 | 7.8 | 10.0 | 9.5 | 10.9 | 14.4 | 16.8 | 14.3 | 19.1 | 15.5 | 16.0 | 13.4 |
| 1887 | 13.0 | 7.8 | 7.7 | 6.3 | 5.9 | 7.8 | 12.4 | 8.1 | 12.0 | 10.0 | 9.7 | 8.8 |
| 1888 | 15.9 | 9.3 | 5.7 | 5.6 | 8.4 | 8.6 | 16.8 | 10.1 | 14.0 | 10.4 | 13.8 | 10.3 |
| 1889 | 12.3 | 6.6 | 6.6 | 6.0 | 5.3 | 8.2 | 18.3 | 9.4 | 11.8 | 10.8 | 11.6 | 9.0 |
| 1890 | 19.3 | 10.8 | 6.7 | 5.4 | 5.6 | 4.9 | 17.1 | 11.4 | 11.3 | 13.6 | 11.8 | 9.9 |
| Mean for 25 years, 1866-1890 | 15.4 | 8.8 | 7.6 | 7.4 | 7.9 | 9.1 | 14.0 | 12.3 | 14.5 | 11.7 | 11.7 | 10.5 |

Table IV gives the results for the fourth quarter of the year, October to December. It shows that for the British Islands generally the warmest fourth quarter was 46.3° in 1866, and the coldest 41.1° in 1887. The warmest district was the southwest of England, where the mean was 46.4°, the coldest was the east of Scotland, where the mean was 41.9°. The rainfall results show that the wettest fourth quarter during the period occurred in 1872 when the total rainfall was 15.9 inches, while during the corresponding period in 1879 the fall was only 4.2 inches, which is the driest fourth quarter during the quarter of a century. The average temperature for the whole of the British Islands for the fourth quarter was 43.7°, which shows a decrease of 14.4° in the period of three months, and the average rainfall was 10.5 inches.

TABLE V.—*Values for the whole year; mean temperature and rainfall for the twenty-five years 1866 to 1890.*

MEAN TEMPERATURE.

| Years. | | Wheat-producing districts. | | | | | Grazing districts. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | North Scotland. | East Scotland. | Northeast England. | East England. | Midland counties. | South England. | West Scotland. | Northwest England. | Southwest England. | North Ireland. | South Ireland. | British Islands generally. |
| | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. |
| 1866 | 45.8 | 46.6 | 46.9 | 49.2 | 48.7 | 49.9 | 48.3 | 48.6 | 51.3 | 48.3 | 49.0 | 48.7 |
| 1867 | 45.4 | 46.5 | 45.9 | 48.3 | 47.9 | 48.6 | 47.4 | 47.8 | 50.2 | 48.5 | 49.3 | 48.0 |
| 1868 | 46.9 | 48.6 | 48.8 | 51.0 | 51.1 | 51.2 | 49.4 | 50.3 | 52.8 | 49.5 | 51.3 | 50.4 |
| 1869 | 45.8 | 47.2 | 47.3 | 48.7 | 49.1 | 49.4 | 48.2 | 48.9 | 51.7 | 49.6 | 50.6 | 49.1 |
| 1870 | 45.8 | 47.0 | 46.5 | 47.9 | 48.6 | 48.5 | 47.4 | 48.2 | 50.4 | 48.5 | 49.7 | 48.3 |
| 1871 | 46.1 | 46.9 | 46.6 | 47.5 | 48.3 | 48.4 | 47.6 | 48.0 | 50.7 | 48.6 | 50.0 | 48.8 |
| 1872 | 46.4 | 47.1 | 47.9 | 49.6 | 49.6 | 50.3 | 48.6 | 49.5 | 51.5 | 48.4 | 49.9 | 49.3 |
| 1873 | 46.1 | 46.9 | 47.3 | 47.9 | 48.3 | 48.9 | 48.1 | 48.4 | 50.4 | 48.2 | 49.6 | 48.4 |
| 1874 | 46.5 | 47.0 | 47.5 | 48.4 | 48.9 | 49.5 | 47.9 | 48.6 | 51.4 | 48.5 | 51.1 | 48.9 |
| 1875 | 46.6 | 47.4 | 47.7 | 48.4 | 48.7 | 49.2 | 48.2 | 48.6 | 50.6 | 48.3 | 51.0 | 48.9 |
| 1876 | 46.3 | 46.9 | 48.0 | 49.2 | 48.9 | 49.9 | 48.0 | 48.8 | 51.1 | 48.1 | 50.8 | 49.0 |
| 1877 | 45.2 | 46.2 | 47.0 | 48.7 | 48.7 | 49.5 | 47.4 | 48.2 | 51.2 | 47.6 | 50.5 | 48.5 |
| 1878 | 46.0 | 47.2 | 47.9 | 48.9 | 49.3 | 50.1 | 48.6 | 49.2 | 50.9 | 49.0 | 50.6 | 49.2 |
| 1879 | 43.8 | 44.1 | 45.0 | 45.8 | 45.8 | 46.9 | 45.6 | 45.9 | 48.4 | 46.1 | 48.3 | 46.2 |
| 1880 | 45.8 | 47.0 | 47.7 | 48.8 | 48.4 | 50.0 | 48.2 | 48.6 | 51.2 | 48.6 | 50.3 | 48.9 |
| 1881 | 44.1 | 45.4 | 46.2 | 47.7 | 47.4 | 49.1 | 46.8 | 47.3 | 49.4 | 47.4 | 49.0 | 47.6 |
| 1882 | 46.2 | 47.3 | 48.4 | 49.1 | 48.7 | 50.4 | 48.2 | 49.0 | 50.3 | 48.7 | 49.8 | 49.0 |
| 1883 | 45.3 | 46.9 | 47.4 | 48.5 | 48.2 | 49.7 | 47.6 | 48.3 | 49.6 | 48.0 | 49.4 | 48.4 |
| 1884 | 46.6 | 47.7 | 48.7 | 49.8 | 49.5 | 51.0 | 48.6 | 49.3 | 50.7 | 48.8 | 50.2 | 49.4 |
| 1885 | 44.4 | 45.9 | 46.8 | 47.5 | 47.3 | 49.0 | 46.4 | 46.9 | 48.7 | 47.2 | 48.6 | 47.5 |
| 1886 | 44.3 | 45.6 | 46.4 | 47.5 | 47.4 | 49.0 | 46.3 | 47.1 | 48.8 | 47.0 | 48.7 | 47.4 |
| 1887 | 45.0 | 46.2 | 46.6 | 47.1 | 47.0 | 48.1 | 46.8 | 47.3 | 48.6 | 48.0 | 49.2 | 47.5 |
| 1888 | 44.4 | 45.1 | 46.1 | 47.0 | 46.7 | 48.2 | 46.7 | 47.1 | 48.8 | 47.5 | 48.9 | 47.2 |
| 1889 | 46.1 | 46.6 | 47.4 | 47.9 | 48.0 | 49.5 | 48.0 | 48.3 | 49.4 | 48.5 | 49.8 | 48.4 |
| 1890 | 46.0 | 46.6 | 47.6 | 47.7 | 47.5 | 49.1 | 47.7 | 48.1 | 49.2 | 48.4 | 49.7 | 48.2 |
| Mean for 25 years, 1866–1890 | 45.6 | 46.6 | 47.2 | 48.3 | 48.3 | 49.3 | 47.7 | 48.3 | 50.4 | 48.2 | 49.8 | 48.4 |

TABLE V.—*Values for the whole year; mean temperature and rainfall for the twenty-five years 1866 to 1890*—Continued.

RAINFALL.

| Years. | North Scotland. | Wheat-producing districts. | | | | | Grazing districts. | | | | | British Islands generally. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | East Scotland. | Northeast England. | East England. | Midland counties. | South England. | West Scotland. | Northwest England. | Southwest England. | North Ireland. | South Ireland. | |
| | In. | In. | In. | In. | In. | In. | In. | In. | In. | In. | In. | In. |
| 1866 | 53.4 | 35.7 | 26.3 | 27.2 | 31.8 | 34.1 | 50.0 | 51.0 | 51.0 | 44.3 | 38.3 | 39.0 |
| 1867 | 48.1 | 33.3 | 24.1 | 24.7 | 27.7 | 29.0 | 43.7 | 40.1 | 46.0 | 43.2 | 36.3 | 34.9 |
| 1868 | 58.7 | 38.5 | 24.1 | 20.7 | 26.8 | 30.2 | 49.5 | 42.9 | 45.6 | 41.7 | 42.1 | 36.3 |
| 1869 | 51.1 | 31.0 | 27.4 | 25.9 | 29.3 | 30.1 | 40.6 | 44.4 | 46.4 | 42.3 | 37.9 | 35.6 |
| 1870 | 40.5 | 25.9 | 23.1 | 20.4 | 20.7 | 22.7 | 33.6 | 35.7 | 37.8 | 37.2 | 32.2 | 29.0 |
| 1871 | 41.8 | 29.0 | 26.4 | 23.1 | 27.3 | 28.7 | 40.5 | 38.9 | 45.0 | 36.9 | 37.0 | 33.3 |
| 1872 | 49.7 | 40.1 | 37.2 | 33.1 | 39.8 | 41.7 | 58.8 | 59.2 | 68.6 | 54.0 | 49.5 | 49.1 |
| 1873 | 50.7 | 34.5 | 20.8 | 21.1 | 24.1 | 26.5 | 42.5 | 36.7 | 43.4 | 37.2 | 36.5 | 32.4 |
| 1874 | 54.8 | 31.8 | 20.7 | 19.1 | 24.1 | 26.6 | 41.9 | 43.6 | 46.8 | 40.0 | 34.7 | 33.0 |
| 1875 | 42.0 | 32.5 | 27.3 | 26.8 | 35.1 | 33.3 | 40.0 | 41.7 | 56.2 | 33.4 | 40.4 | 36.7 |
| 1876 | 44.4 | 36.2 | 31.0 | 27.2 | 34.4 | 33.7 | 44.8 | 44.3 | 49.3 | 40.0 | 42.2 | 38.3 |
| 1877 | 55.9 | 41.2 | 30.3 | 27.7 | 32.9 | 35.1 | 54.4 | 57.0 | 57.1 | 48.2 | 46.7 | 43.1 |
| 1878 | 32.2 | 26.6 | 31.3 | 29.2 | 30.1 | 29.2 | 41.1 | 35.4 | 40.2 | 37.2 | 40.0 | 34.1 |
| 1879 | 28.3 | 29.9 | 26.0 | 31.7 | 29.7 | 32.2 | 40.7 | 34.1 | 39.8 | 37.1 | 39.4 | 34.1 |
| 1880 | 32.4 | 26.3 | 30.2 | 29.0 | 33.7 | 32.4 | 39.9 | 36.4 | 36.4 | 35.4 | 40.9 | 34.1 |
| 1881 | 33.8 | 29.3 | 28.2 | 27.0 | 27.7 | 28.6 | 45.0 | 40.1 | 39.3 | 36.9 | 40.7 | 34.3 |
| 1882 | 37.9 | 32.0 | 30.4 | 30.9 | 36.5 | 31.4 | 51.5 | 43.1 | 50.4 | 41.6 | 45.9 | 39.4 |
| 1883 | 37.9 | 26.3 | 25.9 | 28.9 | 30.8 | 26.5 | 50.6 | 35.4 | 38.5 | 40.0 | 45.3 | 34.9 |
| 1884 | 40.8 | 23.1 | 19.9 | 22.0 | 22.4 | 23.3 | 50.9 | 33.0 | 35.9 | 41.4 | 36.9 | 30.9 |
| 1885 | 35.0 | 21.5 | 23.2 | 27.2 | 27.4 | 27.4 | 42.6 | 31.3 | 39.3 | 33.3 | 39.6 | 31.3 |
| 1886 | 39.1 | 24.9 | 29.2 | 26.2 | 33.1 | 32.9 | 48.1 | 43.0 | 46.5 | 42.8 | 46.5 | 37.3 |
| 1887 | 41.6 | 24.4 | 20.6 | 19.1 | 19.2 | 21.5 | 38.7 | 24.9 | 28.3 | 32.3 | 28.5 | 25.8 |
| 1888 | 43.9 | 30.4 | 25.6 | 24.2 | 26.8 | 28.5 | 46.5 | 31.1 | 38.4 | 36.9 | 39.9 | 32.9 |
| 1889 | 42.0 | 26.0 | 24.1 | 26.3 | 26.8 | 25.6 | 42.4 | 32.4 | 35.9 | 38.5 | 37.6 | 31.6 |
| 1890 | 55.1 | 32.9 | 25.0 | 22.7 | 22.0 | 25.4 | 52.8 | 35.0 | 38.1 | 38.8 | 41.4 | 33.4 |
| Mean for 25 years, 1866–1890 | 43.6 | 30.9 | 26.3 | 25.7 | 28.8 | 29.5 | 45.2 | 39.7 | 44.0 | 39.6 | 39.9 | 35.0 |

Table V gives the results for the whole year. It shows that for the British Islands generally the warmest year in the quarter of a century was 1868, when the mean was 50.4°, and in this year the temperature was highest in all the several districts over the whole of the United Kingdom. The coldest year of the period was 1879, when the mean was 46.2°, and in this year the temperature was lowest in all the districts except the southwest of England, where it was only 0.1° warmer than in the coldest year, which was 1888. The maximum rainfall occurred in 1872, with a total for the whole Kingdom of 49.1 inches; the least annual fall was 25.8 inches in 1887. The years in the early part of the period were generally warmer and wetter than in the latter part of the period, only two out of the last thirteen years having a rainfall in excess of the average. Attention has lately been called to the decrease of fog in recent years. Doubtless this phenomenon is inti-

mately associated with the amount of rain. The average temperature for the whole of the British Islands for the year is 48.4°, and the average rainfall is 35 inches.

In all ordinary years experience proves that wet and dry periods alternately occur. There is, however, one feature in the English climate which is of a permanent nature, and that is the cloudy, damp, and foggy character of our winters. In London, and in a lesser degree in other large towns, to these climatic disadvantages must be added the affliction of smoke. There is no other atmospheric phenomenon which affects so seriously the public health as fog, and its continuance makes a very decided increase in the death returns of the registrar-general. The very vapor to which we owe our fogs, and which, in the form of cloud, conceals the sun for such lengthy periods, is the chief source of warmth in the British Islands during winter. The southwesterly winds, which predominate, blow from off the Atlantic Ocean, where the temperature of the surface water is much warmer than over the Continent of Europe, and without these mild and vapor-bearing winds the English winter would be most rigidly cold. We owe not a little of our warmth in the winter months to the heavy and destructive Atlantic gales which so frequently reach our shores after having traveled over a considerable part of the ocean. At times these gales follow a track which causes their centers to completely traverse the British Islands, and it is in such cases that a large amount of damage is occasioned both on sea and on shore. More frequently, however, we experience merely the warm and moist southerly and westerly winds which constitute the front or advance segment of such storms, the mere outer edge impinging upon our western coasts, and with these conditions much rain usually occurs; but there is, as a rule, very little wind except a freshening southerly breeze or moderate gale on the extreme west and northwest coasts.

The rapid progress which has been made in our knowledge of meteorology of late years dates from the system of charting observations over a fairly large area of the earth's surface, thereby giving a synoptic view of synchronous weather. This method of discussion has exhibited the all-important influence of the permanent areas of high pressure on the general wind systems and shows how the main stream of cyclonic systems or areas of low barometer reading are compelled to skirt the outer regions of the high barometer areas, keeping the high barometer to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This system of charting observations has not been generally adopted for more than about thirty years; and if meteorologists are at present unable to forecast coming weather with sufficient accuracy or for more than a few days in advance, we now understand the many changes which occur and can see law and order in these, where half a century ago all seemed chaos and disorder. Types of weather are now given which have associated with them entirely

different conditions, but the scope of this paper will not admit of more than the most general reference to these, although their importance to meteorology is immense.

Plate XXVI gives a picture of an anticyclone over the British Islands and exhibits the quiet conditions of wind, barometer, and weather which prevail during its continuance, and with it is associated a low temperature in winter and a high temperature in summer. With all such conditions there is a persistency of the weather to maintain a similar character for several days together, and such persistency is at times extended to a month, and even more, the period being very considerably prolonged during the spring and summer of the present year. The central area of the anticyclone seldom maintains a fixed position for more than a day or two, and is constantly undergoing change either from a decrease or acceleration of energy. It is this movement in position of the central area which introduces a very considerable change of weather, although the conditions are in the main fine and dry. If the center is over the northern part of the British Islands, the winds are easterly over the area to the south of the center; but if the center is over the southern portion, then westerly winds prevail over the area to the north of the center, and with these different winds in the United Kingdom the weather is generally of a very different character—and this is true both in winter and summer. There is also a considerable difference in the air associated with an anticyclone, and much of this seems due to whether the high-pressure system has arrived from the westward, from off the Atlantic, or from the eastward, from off the continent of Europe.

Plate XXVII gives a picture of a type of weather with which we in the British Islands have generally very unsettled conditions, with gales in winter and thunderstorms and heavy rain in summer. It is also with these conditions that when once the weather has set in wet there is often a prolonged spell of rainy and unpleasant weather. The principal characteristics of the type are areas of high barometer reading over Scandinavia and over Spain or the south of France, while in the hollow between these two waves of high atmospheric pressure there is a path opened for the passage of cyclonic disturbances, which often form within the region of the British Islands or at a short distance to the westward of our shores. The clearance of the weather after the passage of these disturbances is for the most part of a very temporary character, and other disturbances quickly follow.

The conditions which perhaps of all others are the most puzzling to the forecaster are those when a secondary or subsidiary disturbance is formed in the rear of its parent disturbance. These subsidiaries on the European side of the Atlantic are invariably formed in the southwestern segment of the storm area, and they pass quickly along its southern side, often developing greater energy in a few hours than that

possessed by the original storm system, while it is with these that in England our heaviest rains frequently occur.

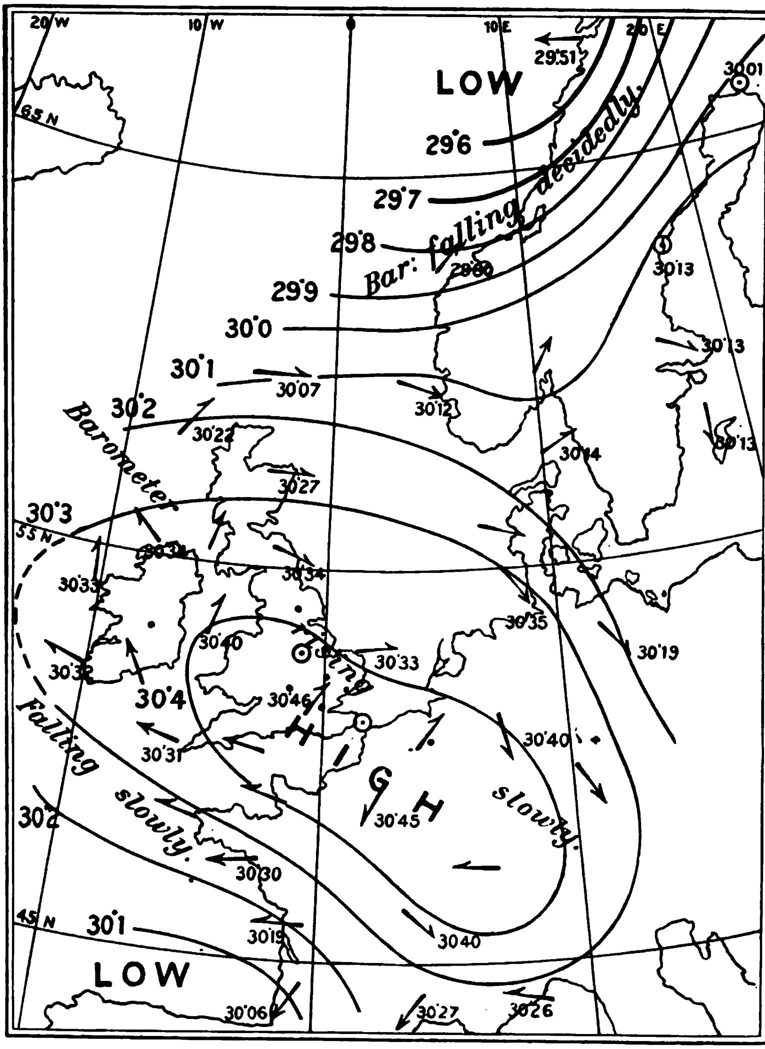
The upper cloud observations often afford very valuable information of an incoming storm, and in the forecasting of subsidiary disturbances the direction of the cirrus and its compounds is of the highest possible value—the threads floating away from the northwestward when the surface wind has set in from the south or southwest, and when the new storm area is on its passage to the northeastward of the observer.

As a record of climate, the meteorological office has instituted two additions since about the year 1881, which will in time, when a sufficient number of years' observations have been accumulated, be of immense value to the meteorologist. In the first place, it has supplied its stations with sunshine recorders, and for the several districts of the United Kingdom the hours of sunshine are published week by week. It also publishes each week the accumulated temperature since the commencement of the year, which element indicates the combined amount and duration of the excess or defect of temperature above or below 42° F., the difference being expressed in "Day-degrees"—a Day degree signifying 1° continued for twenty-four hours, or any other number of degrees for an inversely proportional number of hours. This latter element, it is hoped, will be of considerable use for agricultural purposes, and it has an important bearing on plant growth.

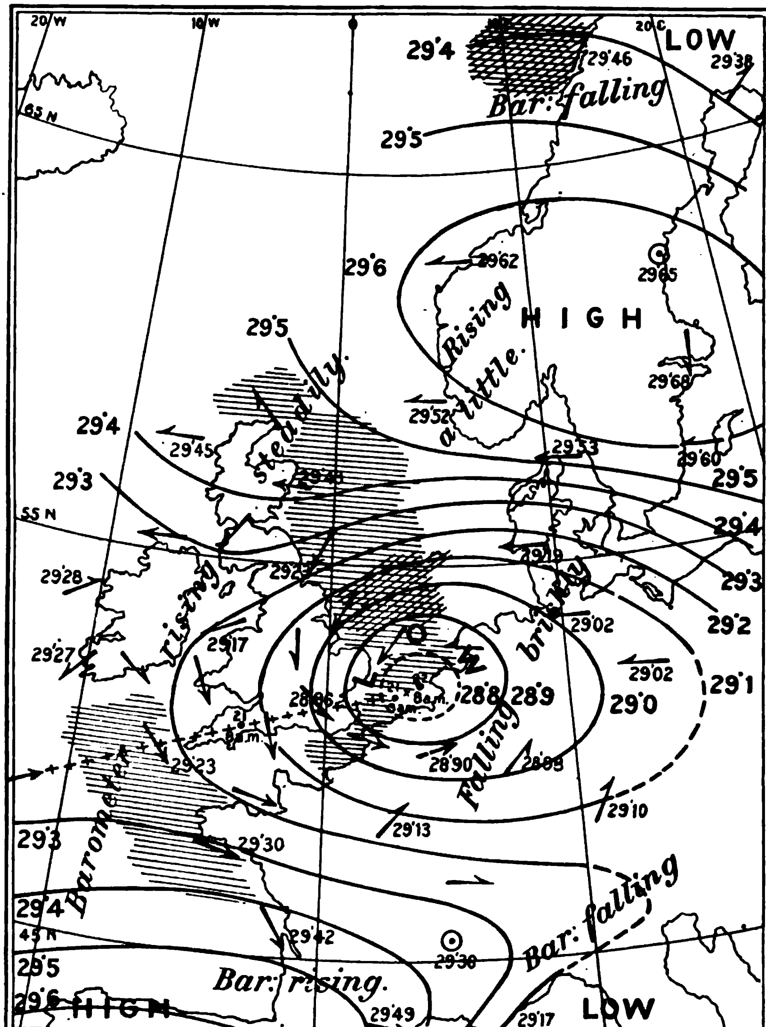
The following figures have been worked by the author from the observations made at the Greenwich Observatory, and it is thought that the table will afford material for detecting any periodicity in seasonal change, and at the same time shows for half a century the difference between the individual summers and winters, both as regards temperature and rainfall. At the cost of somewhat considerable labor the author has tabulated from the published Greenwich volumes the maximum and minimum temperatures for each day during the half century, and it is from these that the frequency of high summer and low winter readings have been obtained.

TABLE VI.—*Temperature and rainfall at Greenwich Observatory in summer and winter for the fifty years 1841 to 1890.*

| Summer—April to September. | | | | | | | Winter—October to March. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year. | Mean temperature. | Days with max. temp. of 70° F. and above. | Days with max. temp. of 80° F. and above. | Highest temperature. | Date. | Total rainfall. | Year. | Mean temperature. | Days with min. temp. of 32° F. and below. | Days with min. temp. below 20° F. | Lowest temperature. | Date. | Total rainfall. |
| | ° F. | | | ° F. | | Ins. | | ° F. | | | ° F. | | Ins. |
| 1841.... | 56.1 | 61 | 3 | 82.8 | May 27 | 16.43 | 1841–2... | 41.8 | 58 | 0 | 22.6 | Nov. 17 | 16.02 |
| 1842.... | 57.2 | 84 | 17 | 90.5 | Aug. 10 | 13.20 | 1842–3... | 42.0 | 41 | 0 | 20.3 | Feb. 15 | 10.65 |
| 1843.... | 56.4 | 60 | 7 | 89.8 | July 5 | 13.27 | 1843–4... | 41.9 | 47 | 1 | 18.8 | Jan. 3 | 13.99 |
| 1844.... | 56.9 | 70 | 11 | 87.6 | June 24 | 7.29 | 1844–5... | 38.8 | 72 | 4 | 7.7 | Feb. 12 | 13.71 |
| 1845.... | 54.5 | 51 | 6 | 86.0 | June 12 | 11.72 | 1845–6... | 44.8 | 29 | 0 | 26.1 | Mar. 21 | 10.95 |
| 1846.... | 59.1 | 108 | 32 | 93.3 | July 5 | 12.34 | 1846–7... | 40.2 | 76 | 9 | 11.2 | Feb. 12 | 11.32 |
| 1847.... | 56.9 | 72 | 26 | 89.4 | July 12 | 8.07 | 1847–8... | 44.1 | 45 | 1 | 16.8 | Jan. 28 | 12.90 |
| 1848.... | 56.9 | 76 | 7 | 84.5 | July 14 | 15.95 | 1848–9... | 44.4 | 40 | 1 | 19.9 | Jan. 3 | 11.65 |
| 1849.... | 57.0 | 85 | 11 | 84.1 | July 8 | 12.58 | 1849–50.. | 42.2 | 61 | 1 | 18.8 | Dec. 29 | 9.60 |
| 1850.... | 56.9 | 64 | 14 | 87.0 | July 16 | 11.42 | 1850–1... | 42.5 | 24 | 0 | 23.7 | Feb. 17 | 13.11 |
| 1851.... | 56.0 | 68 | 9 | 87.0 | June 27 | 12.15 | 1851–2... | 42.3 | 51 | 0 | 21.3 | Mar. 5 | 8.05 |
| 1852.... | 56.8 | 75 | 21 | 90.3 | July 5 | 17.39 | 1852.3... | 43.1 | 44 | 0 | 20.5 | Feb. 19 | 17.04 |
| 1853.... | 55.7 | 64 | 2 | 81.7 | July 7 | 17.92 | 1853–4... | 41.6 | 56 | 8 | 13.5 | Jan. 3 | 9.91 |
| 1854.... | 56.1 | 81 | 14 | 88.7 | July 25 | 10.35 | 1854–5... | 38.9 | 77 | 12 | 11.1 | Feb. 19 | 10.18 |
| 1855.... | 55.9 | 82 | 3 | 83.5 | June 6 | 11.34 | 1855–6... | 41.6 | 37 | 0 | 16.9 | Dec. 22 | 12.63 |
| 1856.... | 56.3 | 78 | 15 | 89.8 | Aug. 2 | 13.45 | 1856–7... | 41.8 | 64 | 2 | 18.5 | Dec. 28 | 8.62 |
| 1857.... | 59.0 | 100 | 35 | 92.7 | June 28 | 11.43 | 1857–8... | 43.1 | 60 | 0 | 20.9 | Jan. 6 | 9.35 |
| 1858.... | 58.1 | 104 | 26 | 94.5 | June 16 | 10.81 | 1858–9... | 43.8 | 32 | 0 | 20.5 | Nov. 24 | 6.65 |
| 1859.... | 58.9 | 98 | 33 | 93.0 | July 18 | 14.15 | 1859–60.. | 41.2 | 66 | 3 | 14.0 | Dec. 19 | 13.44 |
| 1860.... | 54.0 | 28 | 0 | 76.5 | May 23 | 20.28 | 1860–1... | 41.5 | 46 | 8 | 8.0 | Dec. 25 | 11.35 |
| 1861.... | 56.6 | 91 | 11 | 89.3 | Aug. 12 | 8.75 | 1861–2... | 43.3 | 35 | 0 | 20.4 | Jan. 19 | 12.99 |
| 1862.... | 56.5 | 64 | 1 | 81.5 | May 6 | 13.87 | 1862–3... | 44.1 | 31 | 0 | 24.8 | Nov. 23 | 10.57 |
| 1863.... | 56.4 | 66 | 13 | 86.0 | July 15 | 11.26 | 1863–4... | 42.6 | 50 | 2 | 14.3 | Jan. 7 | 8.66 |
| 1864.... | 56.9 | 74 | 15 | 88.6 | Aug. 5 | 8.08 | 1864–5... | 40.4 | 67 | 6 | 15.5 | Feb. 15 | 10.50 |
| 1865.... | 60.1 | 127 | 21 | 87.6 | June 23 | 13.62 | 1865–6... | 44.0 | 32 | 0 | 22.5 | Mar. 1 | 18.50 |
| 1866.... | 56.6 | 57 | 12 | 87.2 | July 13 | 15.96 | 1866–7... | 42.9 | 52 | 7 | 6.6 | Jan. 5 | 11.71 |
| 1867.... | 57.3 | 78 | 9 | 89.0 | Aug. 14 | 17.64 | 1867–8... | 42.3 | 54 | 0 | 21.2 | Dec. 9 | 11.07 |
| 1868.... | 60.4 | 108 | 40 | 96.6 | July 22 | 9.41 | 1868–9... | 43.5 | 39 | 0 | 26.1 | Nov. 6 | 15.87 |
| 1869.... | 55.5 | 71 | 14 | 90.9 | July 22 | 10.43 | 1869–70.. | 40.9 | 63 | 2 | 19.4 | Feb. 11 | 11.00 |
| 1870.... | 58.1 | 91 | 27 | 90.2 | June 22 | 6.80 | 1870–1... | 41.2 | 60 | 7 | 9.8 | Dec. 25 | 11.91 |
| 1871.... | 56.8 | 81 | 15 | 89.2 | Aug. 13 | 14.89 | 1871–2... | 42.7 | 38 | 1 | 18.6 | Dec. 8 | 9.70 |
| 1872.... | 57.4 | 88 | 21 | 90.9 | July 25 | 12.16 | 1872–3... | 42.6 | 46 | 0 | 25.0 | {Feb. 24} {Feb. 25} | 17.04 |
| 1873.... | 56.5 | 76 | 16 | 88.7 | July 22 | 12.21 | 1873–4... | 43.1 | 47 | 0 | 21.0 | Feb. 11 | 7.83 |
| 1874.... | 57.4 | 87 | 16 | 92.0 | July 9 | 10.44 | 1874–5... | 41.3 | 70 | 4 | 18.2 | Jan. 1 | 11.49 |
| 1875.... | 57.9 | 88 | 7 | 85.4 | Aug. 16 | 15.51 | 1875–6... | 41.8 | 57 | 2 | 17.4 | Jan. 8 | 13.02 |
| 1876.... | 57.5 | 83 | 28 | 94.0 | July 17 | 8.74 | 1876–7... | 45.0 | 31 | 0 | 23.5 | Mar. 1 | 18.72 |
| 1877.... | 55.8 | 72 | 12 | 88.2 | July 31 | 11.92 | 1877–8... | 43.6 | 42 | 0 | 24.3 | Mar. 25 | 10.10 |
| 1878.... | 57.0 | 75 | 11 | 85.8 | June 26 | 19.68 | 1878–9... | 39.4 | 77 | 4 | 12.2 | Dec. 25 | 13.28 |
| 1879.... | 54.0 | 30 | 1 | 80.6 | July 30 | 22.03 | 1879–80.. | 40.0 | 71 | 9 | 13.7 | Dec. 7 | 5.54 |
| 1880.... | 56.9 | 76 | 7 | 87.5 | May 26 | 13.76 | 1880–1... | 40.8 | 60 | 10 | 12.7 | Jan. 17 | 18.67 |
| 1881.... | 56.1 | 68 | 17 | 97.1 | July 15 | 12.31 | 1881–2... | 43.8 | 32 | 0 | 21.6 | Dec. 24 | 11.12 |
| 1882.... | 55.7 | 53 | 3 | 81.0 | Aug. 6 | 12.15 | 1882–3... | 42.6 | 44 | 0 | 20.6 | Mar. 24 | 14.75 |
| 1883.... | 56.8 | 73 | 7 | 85.1 | Aug. 21 | 11.28 | 1883–4... | 44.2 | 19 | 0 | 27.3 | Mar. 3 | 9.90 |
| 1884.... | 57.6 | 89 | 27 | 94.2 | Aug. 11 | 8.84 | 1884–5... | 42.3 | 47 | 0 | 22.3 | Jan. 22 | 9.83 |




Anticyclone of March 20, 1893. (Harding.)




CYCLONE OF FEBRUARY 22, 1893. (HARDING.)

TABLE VI.—*Temperature and rainfall at Greenwich Observatory in summer and winter for the fifty years 1841 to 1890*—Continued.

| Summer—April to September. | | | | | | | Winter—October to March. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year. | Mean temperature. | Days with max. temp. of 70° F. and above. | Days with max. temp. of 80° F. and above. | Highest temperature. | Date. | Total rainfall. | Year. | Mean temperature. | Days with min. temp. of 32° F. and below. | Days with min. temp. below 20° F. | Lowest temperature. | Date. | Total rainfall. |
| | ° F. | | | ° F. | | Ins. | | ° F. | | | ° F. | | Ins. |
| 1885.... | 55.8 | 70 | 12 | 90.2 | July 26 | 11.38 | 1885-6... | 39.8 | 71 | 1 | 16.5 | Jan. 7 | 12.75 |
| 1886.... | 57.0 | 80 | 15 | 89.8 | July 6 | 10.80 | 1886-7... | 41.2 | 76 | 7 | 15.5 | Jan. 2 | 11.06 |
| 1887.... | 56.5 | 79 | 27 | 92.2 | July 4 | 10.56 | 1887-8... | 39.3 | 80 | 8 | 18.4 | Feb. 2 | 10.84 |
| 1888.... | 54.7 | 50 | 8 | 89.0 | June 9 | 16.73 | 1888-9... | 41.5 | 60 | 4 | 18.7 | Mar. 4 | 10.59 |
| 1889.... | 56.7 | 74 | 15 | 86.6 | Aug. 1 | 12.79 | 1889-90.. | 42.5 | 42 | 1 | 13.1 | Mar. 4 | 11.25 |
| 1890.... | 56.2 | 73 | 3 | 82.8 | Aug. 5 | 13.34 | 1890-1... | 39.5 | 76 | 10 | 12.0 | Jan. 10 | 7.21 |

Table VI shows that the mean summer temperature at Greenwich is liable to differ by as much as 6°, and that the number of days on which the shade thermometer reached 70° ranges from 127 in the year 1865 to 28 in the year 1860, while the number of days on which the temperature reached 80° ranges from 40 to 0. The mean winter temperature ranges from 45° in 1876–77 to 38.8° in 1844–45, and the number of days with frost ranges from 80 in the winter of 1887–88 to 19 in the winter of 1883–84. The absolute range of temperature in the shade at Greenwich during the fifty years is 97.1° on July 15, 1881, to 6.6° on January 5, 1867.

For real advance in meteorology we require now not so much the accumulation of observations as the master mind which can grasp the truths that are hid to the ordinary worker. It is to such pioneers as Fitz Roy, Loomis, and Ferrel that we owe much of the progress in the past, and for the advancement of our present knowledge we must look to those equally gifted on either side of the Atlantic.

## 5.—THE CLIMATE OF THE NETHERLANDS.

MAURITS SNELLEN.

*Preface.*—In accepting the honorable commission from the chairman of Section C of the World's Congress Auxiliary to give a summary of the climate of the Netherlands, I accepted a task bringing with it its own peculiar difficulties.

It may be supposed that it is easy to give an account of the weather in a country where observations have been made for so many years, but

it is just because the climate of the Netherlands has been so often discussed, and sometimes on a large scale, that it is difficult to decide which particular part of the subject to choose.

Under these circumstances it is scarcely possible to provide anything new; the only thing to do is to give an abstract of notes formerly published on this subject.

This has been done by my eminent predecessor, the late superintendent of the Royal Dutch Meteorological Institute, Prof. Dr. C. H. D. Buys Ballot, in his work[1] "Analytic register of the works published by the R. D. M. Institute," Utrecht, Kemink & Zoon, 1882.

This register contains not only an index of the different subjects in the yearly reports of the institute from 1849 to 1882, but also a complete account of the results of the observations, and a historic review ot the way in which the system of observations was formed and extended in the Netherlands.

After what I have said it will be evident that in the following pages I can only give a *résumé* of all that has been published in the work above quoted, yet sometimes I refer to Dr. Krecke's work "The climate of the Netherlands."

I believe there is no objection whatever to doing this, as the work is not very much known, being written in Dutch. The French translation was taken in hand by the author in the last days of his life, and I hope to be able to bring this to an end myself. I offer the following paper as a part of the preface of this translation, which I would never have published had it not been for the request of Professor Nipher, chairman of the section on climatology.

From all this it is clear that I only write an abridged account of what was written by Prof. Buys Ballot.

*Historic outlines.*—The first notes on the climate of this country date back even before the beginning of the Christian era. Julius Cæsar and Tacitus themselves have mentioned it in their works. The historians of our country only mention a certain number of remarkable phenomena, as storms, inundations, exceptionally dry or wet years causing the destruction of the harvest; but by these examples we only know the extremes, the ordinary condition can not be deduced from them. It was only after the invention of barometers and thermometers in the seventeenth century that a more systematic method of observing atmospheric phenomena was established.

In the beginning of the last century a regular series of observations was made in our country. Wolferdus Senguerdus began at Leyden in 1697. Mr. Josias Eckhardt observed at Breda from 1709 to 1741. The oldest registers were from Musschenbroek. They began in 1729 at Utrecht, and were continued at Leyden from 1740 to 1758. Besides the smaller series mentioned by Wenkebach in his[2] "Contributions to

[1] Beredeneerd register op de werken van het Kon. Ned. Met. Inst. tot 1882.

[2] Bijdragen tot de meteorologie, in het Natuur- en Scheikundig Archief, Deel V.

meteorology," we have especially those by Job Bastert at Flushing, from 1752 to 1775; by Schaaf and Mohr at Amsterdam, from 1759 to 1764 and 1768 to 1782; the observations by Van Swinden at Franeker, from 1771 to 1783; by Brantsen at Arnhem, from 1782 to 1819; by Van der Muelen at Driebergen, from 1759 to 1807; by Staal at Zwolle, from 1849 to 1878, and also the very complete series at Haarlem, from 1788 to 1835, partly coinciding with the above-named series, and with those by Van Dyk at Schiedam, from 1817 to 1835, and the nearly centenary series at Zwanenburg, from 1743 to 1835. Some time afterwards it was there taken up again and continued during the drainage of the Haarlemermeer, so as to determine the influence of the drainage on the climate.

A new series was undertaken by Bruisma at Leeuwarden in 1837, and by Wenkebach at Breda; at the Helder Mr. P. Van der Sterr took very good and regular observations, ordered by the Government engineer. These observations caused scientific researches to be made by P. Van Musschenbroek, Frank Van Berkhey, Van Swinden, and C. Van Lennep.

From these observations they drew several deductions, mostly relating to the climate, yet they were most accurately examined by W. Wenkebach. His "contributions" in the "Physical and chemical records," his inquiry "On the mean atmospheric pressure in the Netherlands, and its monthly changes," and his paper "Sur les temperature et les variations annuelles, mensuelles et diurnes en Neêrlande," give us the history and accurate criticism of former observations and the instruments used. Besides, they contain many hints, which afterwards proved useful to other observers.

About the same time Van Rees made his observations on the top of the Cathedral tower at Utrecht from 1839 to 1843, which were reduced and published by the Society for Arts and Sciences at Utrecht (Utrecht, Van der Post, 1844). The observations especially aimed at the amount of rain on the top and at the foot of the tower, to know the influence of altitude and wind. Symons' observations had about the same results. In the paper of Mr. Van Rees we find some clever remarks, e. g., on the conditions in which two nearly saturated air currents must cause rain showers.

Van Rees also made meteorological observations at the suggestion of Herschel and Quetelet on the 21st of the months of December, March, June, and September, in which we, his students, assisted him. This was the way in which Prof. Buys Ballot and Dr. Krecke became devoted to meteorological observations, and very soon the former succeeded in getting part of a vault in the fortifications of Utrecht for the installation of magnetic instruments. Dr. Krecke began his observations on the 1st of December, 1849, and Prof. Buys Ballot compiled and published them till 1853.

From that moment it can be said that regular and systematic observations were taken, not only in Utrecht but in the Netherlands as a

whole, and negotiations were at once opened with other observers who sent their observations to Utrecht.

It was only on the 1st of February, 1854, after a visit of our well-known minister, Thorbecke, that the present buildings were erected and that the observatory got the title of Royal Dutch Meteorological Institute.

*General remarks.*—The Netherlands belong, according to the partition of Dr. Hann (*Handbuch der Klimatologie*), to the Atlantic region. Yet it must be remarked that the influence of the ocean is not so great as would be expected, owing to the proximity of Great Britain to the westward, and only separated from it by the rather narrow Channel and the North Sea.

The physical condition of the territory must also influence the climate. In the first place, the flatness of the country comes into account. It is only in the southeast, in Belgium, Westphalia, and the so-called Rhineland, that the ground is a little more elevated, and causes undulations not deserving the name of mountains. The sandhills of our country are not worth mentioning.

The surface of our country, consisting of clay, sand, mold, and water, contributes a great deal to the moisture of our climate; the rain penetrates slowly in the sand, and still more slowly in mold and clay, which take a long time to absorb water to a certain depth. This causes an ever moist surface to be in contact with the atmosphere, thus increasing its amount of moisture.

As a consequence of the flatness of the country and the low situation of some parts, even below the sea level, the rain water runs away very slowly, or must be led away by artificial drainage—just the contrary of mountainous countries, where the water penetrates only very little in the ground, but reaches the solid surface very soon by crevasses and fissures, and quickly flows off along the slopes of the mountains and the hills. The expression, "We live on a wet sponge," can be very well applied to our country.

From the flatness of the country the wind can better follow its free course than in mountainous countries, and at the same time it is easy to find an open horizon for observing the phenomena of the atmosphere.

In the following sections we shall try to treat separately the different factors that taken together form the climate.

*Temperature.*—It is not enough to take the averages when wishing to know the influence of the temperature on the climate, even abstracted from the question as to whether averages are of any value at all and ought not to be replaced by the most frequent temperatures. In the first place, it is necessary to know the variations; not only the diurnal and yearly, but also the extraordinary nonperiodical changes, not explicable by ordinary causes. So we must consider:

First. The temperature for each day and month of the year, i. e., its yearly fluctuation.

Second. The temperature for each hour, i. e., its diurnal fluctuation.
Third. The variability in temperature.

(*a*) The mean value of the changes and their limits on both sides in the different seasons and months.
(*b*) The duration of these variations in the same direction.
(*c*) The temperature change from one day to the next.

*The mean daily temperature.*—Long before the series of observations were sufficiently complete to allow the deduction of an average daily temperature with satisfactory accuracy, Prof. Buys Ballot calculated the same by comparison with adjacent places where the series of observations dated from earlier years. They were published in a separate paper, *Changements périodiques de la température, déduits d'Observations néerlandaises de 1729 à 1846*, Utrecht, Kemink et fils, 1847.

The long series of observations made at the castle *Zwanenburg*, near Haarlem, was the basis of this paper. Some years afterwards this calculation was made anew, and published in the *Marche annuelle du thermomètre et du baromètre en Néerlande déduite d'Observations simultanées de 1849 à 1859*, Amsterdam, C. G. van der Post, 1861.

This work was further continued, in that as soon as new observations at another place in the Netherlands were received, the normal temperature for each hour of observation was at once determined. The normals were calculated again in 1876, and published in a new edition of the *Marche annuelle*. But as observations have now been made in our country for a sufficient number of years to calculate from them the mean temperature, I prefer reproducing these instead of the more or less theoretically computed values of the above-mentioned method.

The results of the last thirty years are given in the Meteorological Annual for 1878, page 236. In Table I we give a copy of the same.

In the Annual for 1888 we find a summary for forty years, yet only for the monthly mean temperature, with the remark that it is evident that the daily mean is nearly the same as ten years ago. This is proved by the monthly means for thirty years (1849–'78), for forty years (1849–'88), and the above-indicated normal values as given in Table II.

We remark that the observed numbers correspond more and more with the latter, so that the normal for May ought to be a little higher. As to the rest, Buys Ballot clings more to the normals than to the mean temperatures, even when calculated from a series of forty years. This is the reason why, in Table III, I give a view of the yearly fluctuations of the temperature for a few other stations in the Netherlands, taken from the *Marche annuelle*.

*The hourly average temperature—the diurnal range.*—The daily variation of the temperature for Utrecht was very soon known from the self-recording instruments in connection with the observations at three different hours daily, and the daily readings of the maximum and minimum thermometers.

Table IV gives the same for the middle of each month, as it was

published in 1863 in Dr. Krecke's "The climate of the Netherlands." Subsequent observations made very small changes in these numbers; so it is not worth the trouble to calculate them again.

From this table we see (1) that the lowest temperature occurs in December, about 6 in the morning, and in June between 3 and 4 a. m.; (2) that during the whole year the temperature is highest between 1 and 2 o'clock in the afternoon; (3) that consequently the rising of the temperature is more rapid than the lowering, especially in winter; (4) that the amplitude differs considerably in the different months; in December it is 2.35°; in June, 7.79° C.

These differences are only those between the highest and lowest readings at the same hours. The average daily oscillations or total range, as derived from the readings of the maximum and minimum thermometers, are to be found in Table V. The first column contains the difference between the monthly averages from the readings of the above-mentioned instruments; the second column shows the average difference between the highest and lowest reading in each month from a long series of years. Thus it shows the average monthly oscillation or range.

As we said in the preface, our climate is a coast-land climate, yet a great difference is apparent between the observations at the different stations of our country, according to their more or less proximity to the sea. This is evident from Table VI, where the average daily and monthly oscillations are published for Helder, Flushing, Utrecht, and Maastricht, giving at the same time the latitude and longitude of these places.

The eastern stations, Utrecht and Maastricht, especially the latter, show a much greater oscillation, daily as well as monthly, than the stations on the seaside, Helder and Flushing. There also is a difference between Utrecht and the more eastward and higher station of Maastricht.

*The variability of temperature.*—More characteristic of the climate of a country than the average temperature are its variations.

(*a*) *The average value of these variations and its limits in the different parts of the year.*—In Table VII we give, for a period of forty years (1849–'88), the average monthly temperatures, their differences from the normal temperatures, the greatest variation in the average monthly temperature, positive as well as negative, and the year in which it occurred. This table shows that in winter the negative, in summer the positive, variations are greatest, and also that in winter the variations diverge more than in summer. The absolute highest and lowest thermometer readings are given in Table VIII. It is not possible to speak of real limits; it is probable that after longer series of observations still higher or lower temperatures will be observed than those given in the tables. Therefore only the limits of oscillation in temperature during the period of observation are shown.

(*b*) *Duration of the variations in the same direction.*—"Nothing more

constant than weather," was one of Prof. Buys Ballot's favorite sentences, and to justify this seemingly paradoxical sentence he drew tables to make out the frequency of positive or negative variations during one, two, three, or four consecutive days in a certain period. Thus he found from a series of thirty years (1850–'80) that variations lasting for some days are more frequent than those lasting only for one day. The results are to be found in Table IX; and we find that in thirty years a positive variation during thirteen days occurred fifteen times and a negative fourteen times. With equal chances of duration and diurnal alternation this should have occurred only once. The table extends only to forty-four days, yet it shows that once the temperature remained during fifty-three days (in 1853) below the normal reading.

(c) *Changes from one day to another.*—It is an important question for hygienic studies to know the temperature variations to which the inhabitants are exposed within a day. In a paper concerning the daily average temperature at Helder, published in the "Proceedings of the Royal Academy of Sciences," second series, IX, page 182,[1] Prof. Buys Ballot has calculated the average difference between the temperatures of two consecutive days in all the months of the year. This investigation concerns a period of twenty-five years, not only for Helder, but also for Utrecht and Maastricht. In Table X we find an extract from the same. From this table it is again evident that the regularity of the temperature decreases in proportion to the distance from the seacoast.

*Barometer.*—The variation in atmospheric pressure being of no consequence to the climatology of a country, except in connection with the other elements, we shall not discuss it, and pass at once to the wind.

*Wind.*—Concerning the direction we can only say that in all the seasons and at any time the southwest is most observed; yet some variations occur which will be clear from the following extract from Dr. Krecke's "The Climate of the Netherlands," pages 80 and 81:

> During the winter the southwest wind prevails. On the approach of spring east and northeast winds blow sometimes, becoming more frequent in March and April, so that there is nearly every year a struggle between the polar and equatorial air currents.
>
> In the first days of May the polar current predominates, and is accompanied by a lowering of temperature. Soon afterwards the equatorial air current comes back, supplants, and prevails, though never undisturbed and uncontested, during summer and autumn.
>
> At the end of autumn and beginning of winter a small change in the wind, an inclination to turn westward again, may be observed in some series of observations, but this inclination is small and not general.
>
> In January the direction of the wind is nearest to south, and, in some series of observations, even east of it. This short view of the general yearly range of the wind contains at the same time its explanation. A more exact indication of the greater or smaller prevalence of the stated wind direction is obtained, when at the same time

[1] Verhandelingen van de Koninklijke Academie van Wetenschappen, 2de reeks, Deel IX, p. 182.

the wind force is noticed. The force being greatest in December, February, July, and August, it must be evident that the directions in these months and those next to them have a great superiority over the others. On the contrary, the calculated intensity of the wind is the smallest in March, as winds of opposite direction cause them to lose their superiority.

We find almost the same characteristics in the daily as in the yearly variations of the wind, and the land and sea breeze is very evident in it. When during the time that a southwest or west wind is blowing the temperature rises in the morning after sunrise, the warming increases from east to west as a consequence of the daily rotation of the earth. The temperature of the land increases more than that of the sea, which causes the air to flow toward the land from the sea. At first the supposed direction is very little changed, but as the sun rises higher and higher, the most heated region removes more and more to the southward, and the sea wind thus blows more from the north. In the afternoon the area of greatest warming is to our westward, or rather southwestward, as the land is more extended in that direction. The air current must be turned in that direction wherefore the wind turns still more to the northward. During the night the reverse takes place, and the wind backs to the west and south. The shore wind, which should blow during the night and early morning, is only observed when the wind force is but small; it is mostly surpassed by the prevailing southwest or west wind.

During fine weather of some duration in summer this phenomenon may be often observed. The wind then goes to the north in the evening, and during the night successively to the northeast, east, southeast, and south, thus going through all the points of the compass. Yet this happens only when the atmosphere is quiet over a large area, as it sometimes occurs in July, August, and the beginning of September.

The force of the wind increases regularly from 2 o'clock in the morning till 2 o'clock in the afternoon, to decrease again later. The minimum is for Utrecht, at an average a little less than 3; the maximum, 6.4 kilograms upon the square meter. In the yearly range a maximum is observed in March and a minimum in June or July. For the other meteorological stations in the Netherlands we find great differences from Utrecht, depending upon their proximity to the sea.

Storms occur at all the seasons, but are more frequent in some months than in others. From a series of 137 storms observed at Utrecht we found in—

| | | | |
|---|---|---|---|
| January | 23 | July | 2 |
| February | 29 | August | 5 |
| March | 23 | September | 4 |
| April | 8 | October | 14 |
| May | 5 | November | 9 |
| June | 3 | December | 12 |

A wind blowing for at least a couple of hours with a force of 40 kilograms upon a square meter was regarded as a storm.

Storms generally begin between the south and the west, and the wind nearly always veers, which agrees with the experience that a center of low pressure, which comes so near that it causes a storm, is passing to the northward of the Netherlands. With the rare eastern storms the reverse is observed.

Remarkable storms have been noticed on the following dates:

| Date. | Beginning. | End. | Average force (kilograms per square meter). | Greatest force (kilograms per square meter). | Direction. |
|---|---|---|---|---|---|
| January 30, 1892 | 9 a. m | 10 p. m | 18 | 44 | WSW. |
| March 29, 1892 | ....do | 6 p. m | 18 | 45 | NNE. |
| July 7, 1892 | 10 a. m | 8 p. m | 28 | 72 | SW. |
| September 2, 1892 | Noon | 10 p. m | 25 | 48 | SSW. |
| November 11, 1891 | ....do | ....do | 40 | 99 | SSE., SW., SSW. |
| December 11, 1891 | 3 a. m | 2 p. m | 35 | 90 | SW., SSW. |
| January 26-27, 1890 | 6 a. m | 7 a. m | 33 | 68 | SSW. |
| February 8, 1889 | 1 p. m | 4 p. m | 41 | 55 | SSW., SW., W. |
| February 9, 1889 | 6 a. m | 5 p. m | 38 | 55 | WNW. |
| November 17, 1888 | Noon | 3 p. m | 21 | 48 | SW. |
| May 20, 1887 | 8 a. m | 7 p. m | 29 | 78 | SSW., WSW. |
| October 30, 1887 | 9 a. m | 4 p. m | 49 | 128 | SSW. |
| December 9, 1886 | 1 a. m | 1 p. m | 42 | 66 | SSW. |
| January 23-24, 1884 | 2 p. m | 4 p. m | 38 | 105 | WSW. |
| January 26, 1884 | 9 p. m | Midnight. | 48 | 90 | WSW. |
| October 28, 1884 | 3 a. m | 3 p. m | 36 | 95 | WSW. |
| March 6, 1883 | 2 p. m | 6 p. m | 29 | 70 | NW., NNW. |
| December 11, 1883 | 7 a. m | 7 p. m | 41 | 80 | W. |
| April 29-30, 1882 | 10 p. m | 7 a. m | 38 | 80 | SW. |
| August 23, 1882 | 1 p. m | 4 p. m | 28 | 72 | SW. |
| October 24, 1882 | 4 p. m | 10 p. m | 36 | 71 | SSW. |
| October 14, 1881 | 10 a. m | Midnight. | 44 | 180 | SW. |
| November 26-27, 1881 | 9 p. m | 7 a. m | 41 | 83 | SSW. |
| March 2-3, 1880 | 11 a. m | 4 p. m | 38 | 77 | |

*Rain.*—We find the yearly and monthly rainfall in millimeters observed at Utrecht in Table XI, and for comparison we add the same for some other places in the Netherlands. In general, we may deduce from it that February, March, and April have the minimum, and the last month of the summer and autumn the maximum of rain. Yet this differs largely for different stations. In the eastern part of the country the maximum falls in July, but on the seacoast in October.

For the rainfall as well as for the other elements the variations are of great interest. It is to show this that we give in Tables XII and XIII the periods of dryness and rain of one, two, etc., days between 1874 and 1888. The last line but one in the first of these tables gives the total number of rainless days in these fifteen years; in the second table the number of days on which a measurable rainfall was observed. The last line in Table XII shows how many times an inappreciable rainfall occurred between the rainless days; the last line in Table XIII shows that a rainfall of 0.1 to 0.5 millimeters was observed.

*Thunderstorms.*—Investigations of thunderstorms and their course across the country have been made for many years at the Royal Dutch Meteorological Institute, the accounts of which are to be found in the annuals up to 1880. After that date a special paper was yearly issued, entitled "Thunderstorms in the Netherlands."[1]

From all this material various particulars are to be deduced, of which a general view only can be given in this paper. Table XIV shows how the thunderstorms were distributed through the year, and the hours of the day. These numbers were taken from the annuals for 1868 and 1878. The facts deduced therefrom were plainly con-

[1] Onweders in Nederland.

firmed by subsequent observations. We see from the table that thunderstorms are most frequent in July, and least in January and December. The greatest probability for a thunderstorm during the day is between 2 and 4 p. m.; the least between 4 and 8 a. m. It is not yet possible to say anything positive about the frequency of thunderstorms in the different parts of the country and their course. Prof. Buys Ballot says about this matter in the Analytic Register, page 66:

> I never succeeded in showing the course of thunderstorms as plainly as in Le Verrier's *Atlas des Orages*. It seems to me that in the thunderstorms in our country a higher layer of air precedes and irregularly dips down. It is possible to follow such a thunderstorm for a short time, but it sometimes skips over a large part of the country, while in the rear the storm begins anew, again proceeding for some time in the same direction.

I hope that the few preceding lines will be found sufficient to give a succinct outline of our climate, and to stimulate everyone who might wish to study it more particularly to consult the authorities quoted.

TABLE I.—*The average daily temperature (1849–1878).*

| | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. |
| 1 | 1.58 | 2.91 | 3.65 | 7.54 | 10.03 | 15.16 | 17.03 | 17.99 | 16.58 | 13.26 | 7.29 | 2.29 |
| 2 | 0.55 | 3.04 | 3.95 | 8.12 | 10.23 | 16.70 | 17.07 | 18.16 | 16.57 | 12.77 | 7.12 | 2.39 |
| 3 | 1.54 | 3.30 | 4.55 | 8.24 | 10.81 | 17.15 | 17.24 | 18.35 | 16.44 | 12.46 | 6.60 | 2.68 |
| 4 | 1.84 | 3.11 | 4.63 | 8.22 | 10.27 | 16.68 | 17.55 | 18.31 | 16.85 | 12.88 | 7.08 | 2.94 |
| 5 | 1.50 | 3.56 | 4.26 | 8.48 | 10.90 | 16.96 | 17.53 | 18.37 | 16.75 | 12.39 | 7.00 | 2.67 |
| 6 | 1.65 | 4.02 | 3.90 | 8.79 | 11.30 | 16.94 | 17.82 | 18.15 | 16.76 | 11.83 | 6.72 | 4.34 |
| 7 | 1.77 | 3.04 | 3.83 | 8.90 | 11.80 | 16.75 | 18.00 | 18.23 | 16.07 | 12.59 | 7.10 | 4.22 |
| 8 | 1.27 | 2.93 | 3.46 | 9.01 | 11.82 | 15.83 | 18.04 | 18.68 | 15.97 | 11.76 | 6.98 | 3.44 |
| 9 | 1.64 | 2.05 | 4.21 | 9.00 | 12.19 | 16.28 | 17.85 | 18.14 | 15.86 | 11.48 | 6.67 | 2.82 |
| 10 | 1.65 | 1.40 | 3.49 | 9.02 | 12.28 | 16.05 | 18.24 | 18.24 | 15.66 | 10.87 | 5.39 | 3.34 |
| 11 | 1.47 | 1.42 | 3.79 | 8.88 | 13.15 | 16.41 | 18.34 | 18.29 | 15.60 | 11.45 | 4.82 | 3.06 |
| 12 | 1.65 | 1.25 | 3.99 | 8.68 | 12.77 | 16.65 | 18.60 | 18.66 | 15.34 | 10.87 | 4.21 | 3.08 |
| 13 | 1.29 | 1.54 | 4.14 | 8.43 | 12.09 | 16.77 | 19.18 | 19.21 | 15.31 | 10.94 | 4.53 | 3.29 |
| 14 | 2.07 | 2.20 | 4.65 | 9.31 | 12.00 | 16.49 | 19.43 | 19.27 | 14.65 | 11.04 | 4.91 | 2.75 |
| 15 | 1.44 | 3.44 | 4.45 | 9.63 | 12.65 | 16.90 | 20.17 | 18.89 | 14.80 | 10.77 | 5.29 | 3.38 |
| 16 | 1.72 | 3.69 | 4.78 | 9.73 | 13.39 | 16.89 | 19.36 | 18.91 | 14.75 | 10.41 | 5.18 | 3.40 |
| 17 | 2.17 | 3.70 | 4.96 | 9.16 | 13.38 | 16.64 | 19.10 | 18.03 | 14.93 | 10.31 | 4.56 | 3.26 |
| 18 | 2.42 | 3.07 | 4.62 | 9.44 | 14.17 | 16.65 | 18.57 | 17.73 | 14.53 | 10.25 | 4.31 | 2.84 |
| 19 | 2.56 | 3.47 | 4.46 | 10.34 | 13.56 | 17.26 | 18.57 | 18.09 | 14.32 | 10.77 | 4.04 | 2.70 |
| 20 | 2.02 | 3.05 | 4.61 | 11.27 | 14.18 | 17.62 | 18.64 | 18.18 | 14.08 | 9.97 | 3.57 | 3.40 |
| 21 | 1.49 | 2.70 | 4.76 | 10.70 | 14.12 | 17.54 | 19.27 | 17.68 | 13.78 | 9.52 | 3.08 | 1.27 |
| 22 | 1.62 | 3.03 | 4.62 | 10.75 | 14.39 | 17.57 | 19.83 | 17.60 | 13.36 | 9.88 | 4.36 | 1.61 |
| 23 | 2.42 | 3.13 | 5.11 | 9.88 | 15.08 | 18.05 | 19.92 | 17.22 | 13.78 | 9.49 | 4.38 | 1.17 |
| 24 | 2.84 | 3.31 | 5.43 | 9.85 | 14.08 | 17.62 | 19.06 | 17.69 | 13.35 | 9.08 | 3.61 | 1.46 |
| 25 | 2.35 | 3.61 | 5.55 | 10.44 | 14.58 | 17.84 | 18.89 | 17.46 | 13.61 | 8.58 | 3.62 | 1.14 |
| 26 | 2.25 | 3.88 | 5.85 | 9.61 | 14.46 | 17.85 | 18.71 | 17.32 | 13.51 | 8.30 | 3.94 | 1.47 |
| 27 | 2.19 | 3.86 | 6.03 | 10.48 | 15.15 | 18.01 | 18.45 | 17.35 | 13.88 | 7.79 | 3.83 | 2.35 |
| 28 | 1.94 | 3.78 | 6.47 | 9.63 | 14.99 | 17.87 | 18.45 | 16.92 | 14.59 | 8.02 | 3.66 | 1.70 |
| 29 | 2.78 | ...... | 6.77 | 9.43 | 15.17 | 17.33 | 18.16 | 16.56 | 14.36 | 7.57 | 3.44 | 2.25 |
| 30 | 2.38 | ...... | 7.14 | 9.90 | 14.96 | 16.83 | 18.31 | 16.48 | 13.91 | 7.82 | 2.83 | 2.43 |
| 31 | 2.49 | ...... | 7.72 | ...... | 14.98 | ...... | 18.60 | 16.29 | ...... | 7.36 | ...... | 2.07 |

TABLE II.—*The temperature at Utrecht (monthly averages and normals).*

| Month. | Normal. | Average, 1849–1878. | Average, 1849–1888. | Month. | Normal. | Average, 1849–1878. | Average, 1849–1888. |
|---|---|---|---|---|---|---|---|
| | °C. | °C. | °C. | | °C. | °C. | °C. |
| January | 1.47 | 1.94 | 1.65 | August | 18.00 | 17.96 | 17.83 |
| February | 2.90 | 2.99 | 2.96 | September | 15.14 | 14.90 | 14.97 |
| March | 4.85 | 4.96 | 4.91 | October | 10.36 | 10.39 | 10.14 |
| April | 9.36 | 9.39 | 9.27 | November | 5.18 | 4.98 | 5.07 |
| May | 13.60 | 13.10 | 13.07 | December | 2.61 | 2.65 | 2.71 |
| June | 16.89 | 16.99 | 16.80 | | | | |
| July | 18.39 | 18.52 | 18.40 | Year | 9.90 | 9.91 | 9.81 |

TABLE III.—*Monthly normal temperatures.*

| Months. | Helder, Long. 4° 46′ E., Lat. 52° 58′ N. | Maastricht, Long. 5° 41′ E., Lat. 50° 51′ N. | Utrecht, Long. 5° 7′ E., Lat. 52° 5′ N. | Groningen, Long. 6° 25′ E., Lat. 53° 13′ N. | Leeuwarden, Long. 5° 47′ E., Lat. 53° 12′ N. | Assen, Long. 6° 34′ E., Lat. 52° 59′ N. | Amsterdam, Long. 4° 53′ E., Lat. 52° 23′ N. | Hellevoetsluis, Long. 4° 8′ E., Lat 51° 49′ N. |
|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. |
| January | 1.80 | 1.90 | 1.47 | 0.78 | 1.06 | 0.43 | 1.69 | 1.61 |
| February | 3.16 | 3.61 | 2.90 | 2.43 | 2.70 | 2.14 | 3.34 | 3.32 |
| March | 4.20 | 6.29 | 4.85 | 4.08 | 4.27 | 4.35 | 4.75 | 5.13 |
| April | 7.94 | 10.53 | 9.36 | 8.28 | 8.76 | 8.84 | 8.79 | 9.50 |
| May | 11.86 | 15.45 | 13.60 | 12.70 | 12.99 | 13.43 | 12.82 | 14.08 |
| June | 15.30 | 18.75 | 16.89 | 16.27 | 16.64 | 17.21 | 16.02 | 17.20 |
| July | 17.38 | 20.12 | 18.39 | 18.06 | 18.32 | 18.59 | 17.76 | 18.86 |
| August | 17.59 | 19.25 | 18.00 | 17.53 | 17.96 | 18.07 | 17.58 | 18.50 |
| September | 15.42 | 16.14 | 15.14 | 14.73 | 15.04 | 14.76 | 15.36 | 15.98 |
| October | 11.06 | 11.47 | 10.36 | 10.01 | 10.18 | 9.86 | 10.80 | 11.45 |
| November | 6.63 | 6.15 | 5.18 | 5.14 | 5.33 | 4.47 | 5.95 | 5.95 |
| December | 3.86 | 3.57 | 2.61 | 2.47 | 2.66 | 2.02 | 3.50 | 3.28 |
| Year | 9.65 | 11.08 | 9.90 | 9.38 | 9.64 | 9.56 | 9.94 | 10.41 |

TABLE IV.—*Hourly average temperature.*

| Hours. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. |
| 1 a. m. | 0.88 | 0.93 | 1.71 | 5.43 | 8.82 | 12.71 | 14.35 | 14.55 | 11.89 | 8.54 | 3.55 | 2.23 |
| 2 a. m. | 0.74 | 0.77 | 1.51 | 5.18 | 8.54 | 12.41 | 14.09 | 14.29 | 11.62 | 8.35 | 3.42 | 2.10 |
| 3 a. m. | 0.60 | 0.47 | 1.34 | 4.96 | 8.29 | 12.16 | 13.88 | 14.05 | 11.42 | 8.18 | 3.27 | 1.98 |
| 4 a. m. | 0.51 | 0.33 | 1.18 | 4.82 | 8.21 | 12.18 | 13.83 | 13.86 | 11.25 | 8.01 | 3.18 | 1.86 |
| 5 a. m. | 0.42 | 0.20 | 1.11 | 4.93 | 8.72 | 12.99 | 14.30 | 13.90 | 11.13 | 7.90 | 3.06 | 1.75 |
| 6 a. m. | 0.25 | 0.15 | 1.26 | 5.64 | 9.97 | 14.51 | 15.73 | 14.84 | 11.31 | 7.92 | 3.00 | 1.70 |
| 7 a. m. | 0.42 | 0.28 | 1.96 | 6.81 | 11.36 | 15.93 | 17.24 | 16.40 | 12.52 | 8.26 | 3.04 | 1.86 |
| 8 a. m. | 0.65 | 0.73 | 2.84 | 8.01 | 12.58 | 17.21 | 18.44 | 17.88 | 14.16 | 9.09 | 3.89 | 1.96 |
| 9 a. m. | 1.08 | 1.39 | 3.78 | 9.00 | 13.44 | 18.12 | 19.27 | 18.83 | 15.36 | 10.05 | 4.00 | 2.40 |
| 10 a. m. | 1.65 | 2.21 | 4.69 | 9.83 | 14.19 | 18.80 | 19.91 | 19.59 | 16.29 | 11.12 | 4.75 | 2.89 |
| 11 a. m. | 2.21 | 3.00 | 5.41 | 10.46 | 14.76 | 19.32 | 20.27 | 20.16 | 16.98 | 11.96 | 5.45 | 3.39 |
| Noon | 2.70 | 3.60 | 6.10 | 10.97 | 15.26 | 19.68 | 20.61 | 20.61 | 17.46 | 12.55 | 6.00 | 3.80 |
| 1 p. m. | 3.08 | 3.91 | 6.47 | 11.27 | 15.53 | 19.95 | 20.87 | 20.91 | 17.80 | 12.99 | 6.36 | 4.05 |
| 2 p. m. | 3.07 | 4.14 | 6.55 | 11.33 | 15.51 | 19.88 | 20.81 | 20.83 | 17.86 | 13.02 | 6.42 | 4.03 |
| 3 p. m. | 3.05 | 4.13 | 6.50 | 11.21 | 15.50 | 19.79 | 20.73 | 20.68 | 17.58 | 12.79 | 6.22 | 4.00 |
| 4 p. m. | 2.68 | 3.81 | 6.17 | 10.85 | 15.12 | 19.37 | 20.41 | 20.32 | 17.09 | 12.20 | 5.70 | 3.68 |
| 5 p. m. | 2.22 | 3.18 | 5.56 | 10.19 | 14.43 | 18.69 | 19.79 | 19.66 | 16.34 | 11.36 | 5.13 | 3.33 |
| 6 p. m. | 1.88 | 2.64 | 4.74 | 9.31 | 13.66 | 17.81 | 19.07 | 18.82 | 15.33 | 10.62 | 4.74 | 3.08 |
| 7 p. m. | 1.59 | 2.17 | 3.97 | 8.35 | 12.72 | 16.86 | 18.12 | 17.78 | 14.44 | 10.07 | 4.43 | 2.88 |
| 8 p. m. | 1.38 | 1.79 | 3.37 | 7.56 | 11.68 | 15.77 | 17.11 | 16.86 | 13.79 | 9.64 | 4.17 | 2.74 |
| 9 p. m. | 1.21 | 1.52 | 2.89 | 6.91 | 10.86 | 14.77 | 16.18 | 16.05 | 13.24 | 9.26 | 3.96 | 2.65 |
| 10 p. m. | 1.12 | 1.31 | 2.53 | 6.43 | 10.21 | 14.02 | 15.50 | 15.51 | 12.84 | 8.97 | 3.83 | 2.58 |
| 11 p. m. | 1.04 | 1.17 | 2.28 | 6.10 | 9.79 | 13.53 | 15.07 | 15.12 | 12.48 | 8.75 | 3.69 | 2.55 |
| Midnight | 0.96 | 1.00 | 2.03 | 5.80 | 9.39 | 13.12 | 14.72 | 14.75 | 12.15 | 8.53 | 3.55 | 2.45 |

TABLE V.—*The average daily and monthly ranges of temperature.*

| Month. | 1851–1862. | |
|---|---|---|
| | Daily. | Monthly. |
| | °C. | °C. |
| January | 4.06 | 18.0 |
| February | 5.14 | 17.3 |
| March | 6.60 | 19.3 |
| April | 7.68 | 20.2 |
| May | 8.43 | 22.3 |
| June | 8.81 | 20.8 |
| July | 8.23 | 18.9 |
| August | 8.31 | 18.8 |
| September | 7.61 | 17.7 |
| October | 6.30 | 17.7 |
| November | 4.48 | 17.9 |
| December | 3.73 | 17.0 |

TABLE VI.—*Daily and monthly oscillation of temperature.*

| Month. | Helder, Long. 4° 46′ E., Lat. 52° 58′ N. | | Flushing, Long. 3° 37′ E., Lat. 51° 27′ N. | | Utrecht, Long. 5° 7′ E., Lat. 52° 5′ N. | | Maastricht, Long. 5° 41′ E., Lat. 50° 51′ N. | |
|---|---|---|---|---|---|---|---|---|
| | Daily. | Monthly. | Daily. | Monthly. | Daily. | Monthly. | Daily. | Monthly. |
| | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. |
| January | 3.30 | 14.3 | 3.55 | 14.8 | 4.06 | 18.0 | 4.78 | 20.0 |
| February | 3.77 | 13.7 | 4.68 | 13.4 | 5.14 | 17.3 | 5.83 | 20.0 |
| March | 4.40 | 14.6 | 5.12 | 15.6 | 6.60 | 19.3 | 7.62 | 22.3 |
| April | 4.86 | 15.3 | 6.48 | 18.9 | 7.68 | 20.2 | 9.31 | 23.7 |
| May | 5.22 | 16.4 | 6.68 | 18.9 | 8.43 | 22.3 | 10.22 | 25.1 |
| June | 5.73 | 17.1 | 7.56 | 19.6 | 8.81 | 20.8 | 10.20 | 23.7 |
| July | 5.67 | 14.2 | 6.44 | 18.2 | 8.23 | 18.9 | 10.19 | 22.2 |
| August | 5.37 | 14.1 | 6.68 | 17.7 | 8.31 | 18.8 | 10.16 | 21.6 |
| September | 4.76 | 13.2 | 5.76 | 14.3 | 7.61 | 17.7 | 9.24 | 20.8 |
| October | 3.91 | 13.3 | 5.40 | 13.1 | 6.30 | 17.7 | 7.93 | 21.6 |
| November | 3.69 | 14.3 | 4.43 | 13.7 | 4.48 | 17.9 | 5.38 | 20.2 |
| December | 3.53 | 14.5 | 3.53 | 14.9 | 3.73 | 17.0 | 4.67 | 20.4 |

TABLE VII.—*The average monthly temperatures.*

| Month. | Average. | Difference from normal (negative in italics). | Greatest positive variation. | | Greatest negative variation. | |
|---|---|---|---|---|---|---|
| | | | Degrees. | Year. | Degrees. | Year. |
| | °C. | °C. | °C. | | °C. | |
| January | 1.65 | 0.18 | 4.08 | 1866 | 4.97 | 1850 |
| February | 2.96 | 0.06 | 3.45 | 1867 | 8.21 | 1855 |
| March | 4.91 | 0.06 | 3.27 | 1862 | 4.28 | 1853 |
| April | 9.27 | *0.09* | 3.04 | 1865 | 2.34 | 1852 |
| May | 13.07 | *0.45* | 3.81 | 1868 | 2.82 | 1876 |
| June | 16.80 | *0.09* | 3.50 | 1858 | 2.65 | 1869 |
| July | 18.40 | 0.01 | 3.43 | 1852 | 2.66 | 1888 |
| August | 17.88 | *0.27* | 3.06 | 1857 | 3.47 | 1881 |
| September | 14.97 | *0.17* | 2.77 | 1865 | 2.46 | 1847 |
| October | 10.14 | *0.22* | 1.76 | 1857 | 3.49 | 1881 |
| November | 5.07 | *0.11* | 3.47 | 1852 | 3.44 | 1858 |
| December | 2.71 | 0.10 | 4.45 | 1852 | 5.90 | 1879 |

TABLE VIII.—*Absolute highest and lowest thermometer readings.*

| Month. | Maximum. | | Minimum. | | Highest. | Lowest. | Month. | Maximum. | | Minimum | | Highest. | Lowest. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Day. | Year. | Day. | Year. | | | | Day. | Year. | Day. | Year. | | |
| | | | | | °C. | °C. | | | | | | °C. | °C. |
| January | 16 | 1852 | 21 | 1850 | 12.6 | —21.0 | July | 23 | 1873 | 1 | 1849 | 33.1 | + 4.9 |
| February | 16 | 1867 | 18 | 1855 | 14.6 | — 17.7 | August | 4 | 1857 | 28 | 1864 | 34.4 | + 5.5 |
| March | 23 | 1871 | 2 | 1853 | 20.8 | — 10.0 | September | 2 | 1871 | 26 | 1855 | 29.5 | — 0.8 |
| April | 23 | 1865 | 8 | 1864 | 25.9 | — 4.0 | October | 5 | 1886 | 27 | 1866 | 24.8 | — 2.1 |
| May | 28 | 1892 | 1 | 1865 | 31.7 | — 2.9 | November | 2 | 1852 | 23 | 1858 | 17.6 | —10.6 |
| June | 15 | 1858 | 14 | 1849 | 33.9 | + 2.5 | December | 7 | 1856 | 8 | 1871 | 14.1 | —20.0 |

TABLE IX.—*Duration of variations in the same direction.*

| Days. | Variation. | | Days. | Variation. | | Days. | Variation. | |
|---|---|---|---|---|---|---|---|---|
| | Positive. | Negative. | | Positive. | Negative. | | Positive. | Negative. |
| 1 | 317 | 272 | 16 | 6 | 9 | 31 | 1 | 2 |
| 2 | 189 | 187 | 17 | 8 | 6 | 32 | 1 | 2 |
| 3 | 130 | 120 | 18 | 4 | 5 | 33 | | |
| 4 | 63 | 81 | 19 | 9 | 8 | 34 | 2 | |
| 5 | 62 | 73 | 20 | 3 | 5 | 35 | | 1 |
| 6 | 47 | 58 | 21 | | 6 | 36 | 1 | |
| 7 | 40 | 40 | 22 | 2 | 5 | 37 | | 1 |
| 8 | 36 | 42 | 23 | 4 | 6 | 38 | 1 | 1 |
| 9 | 36 | 22 | 24 | 1 | 1 | 39 | | 2 |
| 10 | 23 | 14 | 25 | 2 | 2 | 40 | | |
| 11 | 12 | 16 | 26 | 4 | 2 | 41 | | |
| 12 | 16 | 19 | 27 | 1 | 3 | 42 | | |
| 13 | 15 | 14 | 28 | 1 | 3 | 43 | | 1 |
| 14 | 17 | 17 | 29 | | | 44 | | |
| 15 | 9 | 16 | 30 | 1 | | 45 | | |

TABLE X.—*The average difference between the temperatures of two consecutive days.*

| Month. | Helder, 1845–1875. | Utrecht, 1849–1875. | Maastricht, 1851–1875. | Month. | Helder, 1845–1875. | Utrecht, 1849–1875. | Maastricht, 1851–1875. |
|---|---|---|---|---|---|---|---|
| | °C. | °C. | °C. | | °C. | °C. | °C. |
| January | 1.54 | 1.79 | 1.89 | July | 1.39 | 1.68 | 1.90 |
| February | 1.20 | 1.58 | 1.62 | August | 1.06 | 1.48 | 1.61 |
| March | 1.17 | 1.52 | 1.75 | September | 0.99 | 1.29 | 1.50 |
| April | 1.19 | 1.68 | 1.88 | October | 1.13 | 1.29 | 1.66 |
| May | 1.27 | 1.89 | 1.89 | November | 1.52 | 1.65 | 1.78 |
| June | 1.40 | 1.89 | 2.01 | December | 1.47 | 1.84 | 1.96 |

TABLE XI.—*Yearly and monthly rainfall.*

| Cities. | Observed during the years— | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Helder | 1852–89 | 49.2 | 42.8 | 44.3 | 30.1 | 34.0 | 36.7 | 54.8 | 78.9 | 84.1 | 85.0 | 71.0 | 60.3 | 671.2 |
| Maastricht | 1852–89 | 39.6 | 36.8 | 37.7 | 35.0 | 49.1 | 57.6 | 61.8 | 64.5 | 52.3 | 54.6 | 49.3 | 53.0 | 591.8 |
| Utrecht | 1849–89 | 48.1 | 44.7 | 44.7 | 38.5 | 50.1 | 55.2 | 76.6 | 82.7 | 67.1 | 72.8 | 59.1 | 62.7 | 702.3 |
| Groningen | 1852–89 | 45.1 | 42.4 | 41.5 | 34.2 | 45.6 | 57.8 | 71.3 | 86.8 | 69.0 | 66.1 | 61.3 | 51.7 | 672.8 |
| Leeuwarden | 1876–89 | 49.7 | 51.7 | 53.3 | 36.1 | 43.9 | 49.5 | 80.6 | 93.8 | 76.6 | 91.1 | 80.0 | 67.8 | 774.1 |
| Assen | 1852–89 | 43.0 | 42.7 | 42.4 | 29.3 | 50.5 | 58.8 | 70.3 | 82.2 | 68.6 | 64.5 | 56.4 | 52.3 | 661.0 |
| Amsterdam | 1852–89 | 53.4 | 41.2 | 42.8 | 36.0 | 45.4 | 50.3 | 75.5 | 84.2 | 76.1 | 76.8 | 62.7 | 54.4 | 698.8 |
| Hellevoetsluis | 1879–89 | 30.5 | 28.4 | 33.9 | 32.2 | 41.8 | 52.9 | 72.0 | 77.7 | 64.9 | 86.4 | 53.9 | 56.8 | 631.4 |
| Luxemburg | 1854–78 | 68.1 | 52.9 | 52.0 | 47.2 | 64.5 | 55.3 | 67.8 | 64.4 | 66.9 | 68.0 | 69.4 | 74.2 | 745.5 |

TABLE XII.—*Periods of dryness in Utrecht for one, two, three, etc., successive days (1874–1888).*

| Number of days. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Summary. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 18 | 22 | 12 | 13 | 17 | 30 | 27 | 27 | 21 | 16 | 31 | 26 | 260 |
| 2 | 11 | 6 | 5 | 13 | 5 | 11 | 10 | 11 | 10 | 10 | 9 | 6 | 107 |
| 3 | 4 | 6 | 4 | 4 | 11 | 2 | 7 | 10 | 6 | 7 | 9 | 14 | 84 |
| 4 | 3 | 7 | 5 | 6 | 5 | 3 | 4 | 4 | 2 | 4 | 1 | 4 | 48 |
| 5 | 3 | 4 | 2 | 3 | 4 | 5 | 3 | 1 | 3 | 5 | 3 | 5 | 41 |
| 6 | 3 | 3 | 2 | | 5 | 4 | 1 | 1 | 4 | 1 | | 1 | 25 |
| 7 | 1 | 1 | 3 | 2 | 2 | 6 | 2 | 3 | 3 | 1 | 4 | 1 | 29 |
| 8 | 2 | 3 | 2 | | 4 | 2 | 1 | 2 | 1 | 3 | 3 | 1 | 24 |
| 9 | | | | 1 | | | 1 | 2 | 2 | 1 | | | 7 |
| 10 | 1 | | 3 | | | 1 | 2 | 1 | 1 | | | | 9 |
| 11 | 1 | | 1 | 3 | 2 | | 1 | 1 | 1 | 3 | | 1 | 14 |
| 12 | 1 | | | 3 | 1 | | | | 1 | | | | 6 |
| 13 | | 1 | | 1 | 1 | | 1 | | 1 | | | | 5 |
| 14 | 1 | 2 | 1 | | | | | | | 1 | | | 5 |
| 15 | 1 | 1 | 1 | | 2 | 1 | | | | | | 1 | 8 |
| 16 | 1 | | 2 | 1 | | | 1 | 1 | | | | | 5 |
| 17 | | 1 | | 2 | | | | | | 1 | | | 4 |
| 18 | | | | | | | | | 1 | | | | 1 |
| 19 | | | | | | | 1 | | | | | 1 | 2 |
| 20 | | | 1 | | | | | | | | | | 1 |
| 21 | 1 | | | | | | | | | | | | 1 |
| 22 | | | | | | | | | | | | | |
| 23 | | | | | | | | | | | | | |
| 24 | | | | | | | | | | | | | |
| 25 | | | | | | | | | | | | | |
| 26 | | | 1 | 1 | | | | | | | | | 2 |
| 27 | | | | | | | | | | | | | |
| 28 | | | | | | | | | | | | | |
| 29 | | | | | | | | 1 | | | | | 1 |
| 30 | | | | | | 1 | | | | | | | 1 |
| Dry days | 224 | 222 | 261 | 271 | 253 | 232 | 215 | 228 | 217 | 205 | 147 | 187 | 2,662 |
| Days with sprinkles | 27 | 29 | 21 | 27 | 19 | 10 | 18 | 16 | 14 | 14 | 5 | 26 | 226 |

TABLE XIII.—*Periods of rain in Utrecht for one, two, three, etc., successive days (1874–1888).*

| Number of days. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Summary. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 10 | 12 | 20 | 18 | 16 | 24 | 20 | 14 | 10 | 14 | 13 | 176 |
| 2 | 11 | 18 | 14 | 10 | 14 | 18 | 18 | 9 | 10 | 7 | 10 | 11 | 145 |
| 3 | 6 | 7 | 6 | 5 | 13 | 14 | 5 | 12 | 9 | 7 | 9 | 8 | 101 |
| 4 | 7 | 7 | 5 | 5 | 1 | 10 | 6 | 5 | 8 | 8 | 6 | 5 | 68 |
| 5 | 3 | 5 | 1 | 1 | 4 | 2 | 9 | 4 | 5 | 3 | 5 | 3 | 45 |
| 6 | 5 | 4 | 4 | 8 | 3 | 1 | 2 | 3 | 5 | 3 | 3 | 8 | 44 |
| 7 | 3 | 4 | 4 | 4 | 1 | 2 | 3 | 3 | 1 | 1 | 5 | 3 | 34 |
| 8 | 3 | 1 | 1 | ...... | 2 | ...... | 1 | ...... | 1 | 1 | 1 | 1 | 12 |
| 9 | 1 | ...... | ...... | 2 | ...... | 2 | 1 | 1 | 5 | ...... | 2 | 3 | 17 |
| 10 | 1 | ...... | 1 | 1 | ...... | ...... | 1 | 1 | 1 | 3 | 2 | 1 | 12 |
| 11 | ...... | ...... | 1 | ...... | 2 | 1 | 1 | 2 | ...... | 1 | 2 | 1 | 11 |
| 12 | ...... | ...... | 2 | 1 | ...... | ...... | 1 | 1 | ...... | 3 | 1 | 2 | 11 |
| 13 | ...... | ...... | ...... | 1 | ...... | 1 | ...... | 2 | 1 | 1 | ...... | 1 | 7 |
| 14 | ...... | ...... | ...... | ...... | 1 | ...... | 1 | ...... | 1 | 1 | ...... | 2 | 6 |
| 15 | 2 | ...... | ...... | ...... | ...... | ...... | 1 | 1 | 1 | ...... | ...... | ...... | 5 |
| 16 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 1 | 1 | 2 |
| 17 | 1 | ...... | 1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 2 |
| 18 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 19 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 20 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 1 | ...... | ...... | 1 |
| 21 | 1 | 1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 2 |
| 22 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 23 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| 24 | ...... | ...... | 1 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | 1 | ...... | 2 |
| 25 | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... | ...... |
| Rainy days | 255 | 201 | 225 | 179 | 180 | 206 | 246 | 247 | 240 | 249 | 284 | 300 | 2,812 |
| Days with 0.1 to 0.5 mm | 58 | 33 | 51 | 36 | 39 | 36 | 50 | 55 | 50 | 47 | 54 | 48 | 557 |

TABLE XIV.—*Thunderstorms, daily and yearly periods.*

| Time. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 to 2 a.m | ...... | ...... | ...... | 1 | 1 | 1 | 5 | 9 | 1 | 2 | ...... | ...... | 20 |
| 2 to 4 a.m | ...... | ...... | ...... | ...... | 2 | 2 | 12 | 6 | 6 | 2 | ...... | ...... | 30 |
| 4 to 6 a.m | ...... | 1 | ...... | ...... | 8 | 8 | 7 | 6 | ...... | ...... | ...... | 1 | 21 |
| 6 to 8 a.m | ...... | ...... | ...... | 1 | 2 | 2 | 8 | 4 | 1 | ...... | ...... | ...... | 18 |
| 8 to 10 a.m | 1 | ...... | 1 | 1 | 2 | 4 | 19 | 3 | 2 | 2 | 1 | ...... | 36 |
| 10 to noon | ...... | ...... | 1 | 3 | 12 | 8 | 20 | 16 | 7 | 1 | ...... | ...... | 68 |
| 12 to 2 p.m | ...... | ...... | 1 | 4 | 11 | 19 | 18 | 17 | 12 | 6 | ...... | ...... | 88 |
| 2 to 4 p.m | 1 | ...... | 4 | 6 | 19 | 23 | 22 | 19 | 14 | 1 | ...... | ...... | 109 |
| 4 to 6 p.m | 2 | 2 | ...... | 7 | 11 | 15 | 21 | 21 | 9 | 2 | 2 | ...... | 92 |
| 6 to 8 p.m | 1 | 3 | 4 | 4 | 11 | 16 | 22 | 8 | 6 | 4 | 1 | ...... | 80 |
| 8 to 10 p.m | ...... | ...... | ...... | 1 | 7 | 7 | 11 | 12 | 5 | 3 | 1 | ...... | 47 |
| 10 to 12 p.m | ...... | 1 | ...... | ...... | 2 | 1 | 16 | 7 | 3 | 4 | ...... | ...... | 34 |
| Total | 5 | 7 | 11 | 28 | 83 | 101 | 181 | 128 | 66 | 27 | 5 | 1 | 643 |

## 6.—THE CLIMATE OF DENMARK.

ADAM PAULSEN.

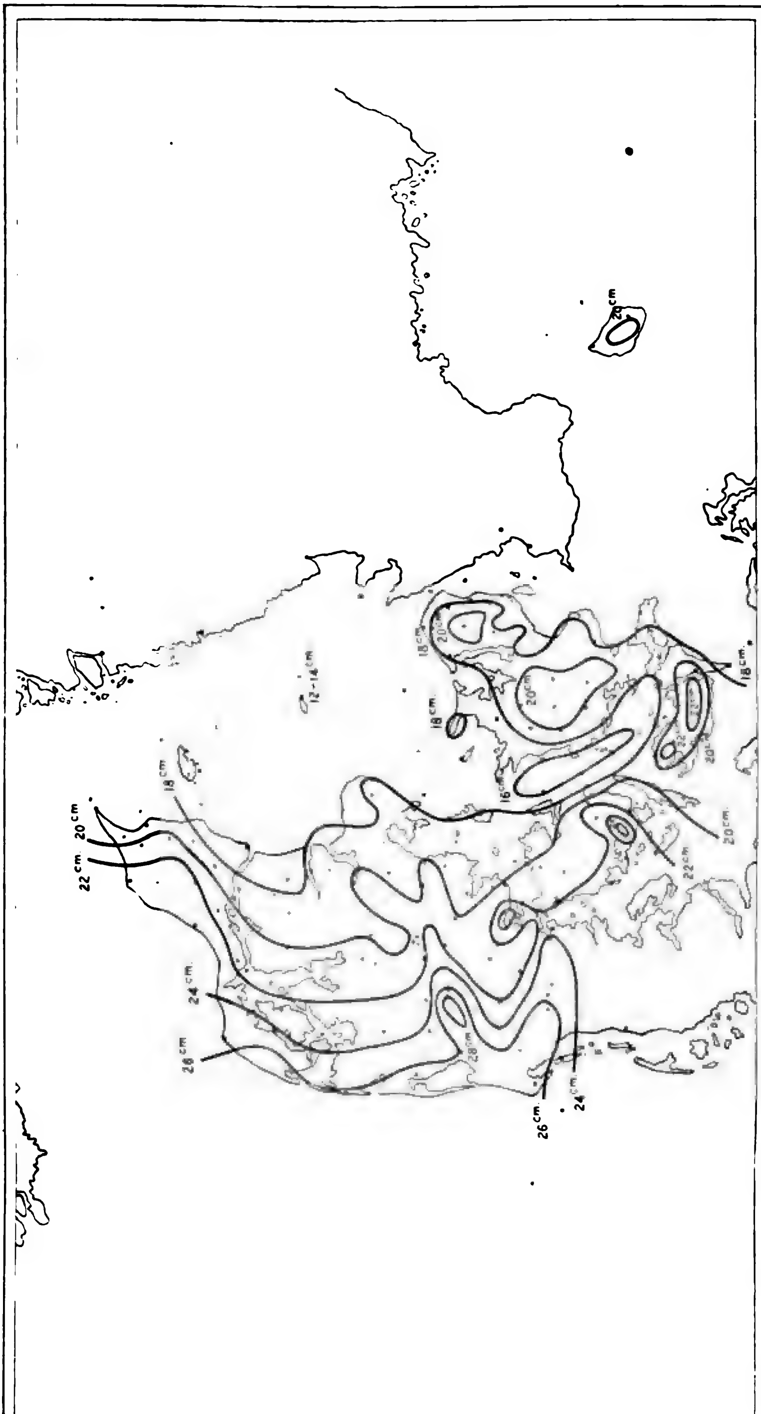
(Plates XXVIII–XXXV.)

Denmark proper is situated between 54° 33½′ and 57° 45′ north latitude, 5° 5′ and 15° 12′ east longitude.

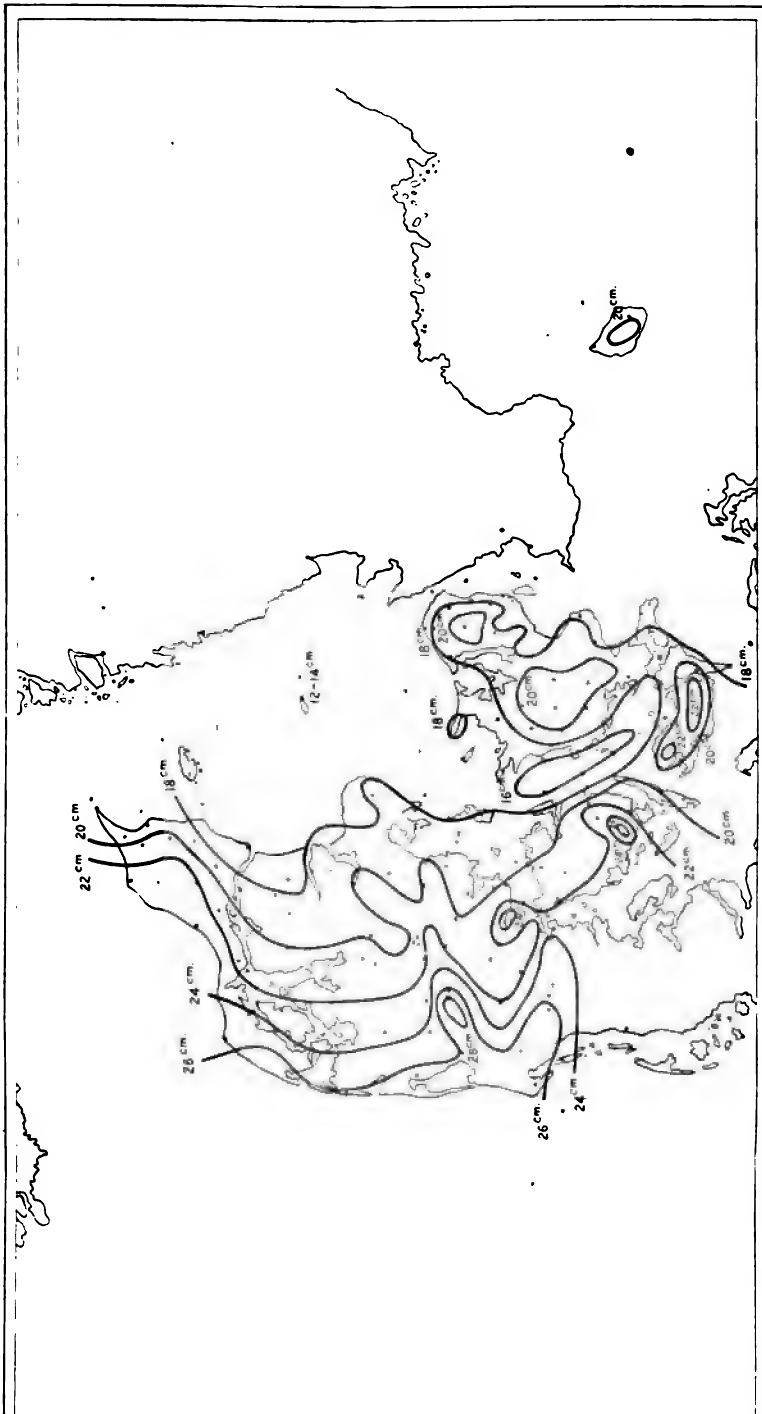
The situation of the country between a large sea, the North Sea, on the west, which sea is in immediate connection with the Atlantic, the smaller inland sea, the Baltic, on the east, the northern part of Central Europe on the south, and finally the Scandinavian Peninsula on the north and northeast, causes the climate to be alternately influenced by these surrounding seas and lands.


ISOHYETALS; NORMAL RAINFALL IN DENMARK, SUMMER, 1861-1885. (PAULSEN.)

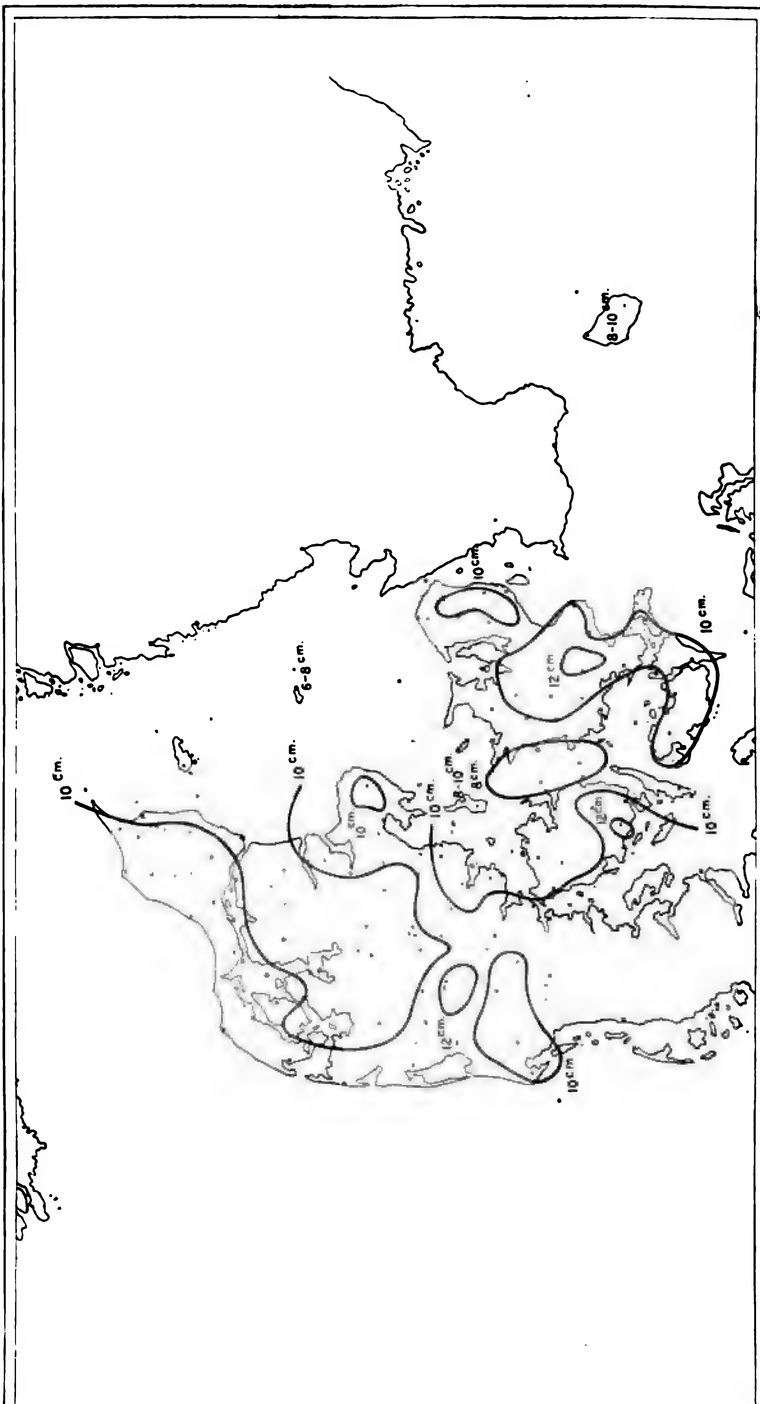

ISOHYETALS: NORMAL RAINFALL IN DENMARK, WINTER, 1861-1885. (PAULSEN.)



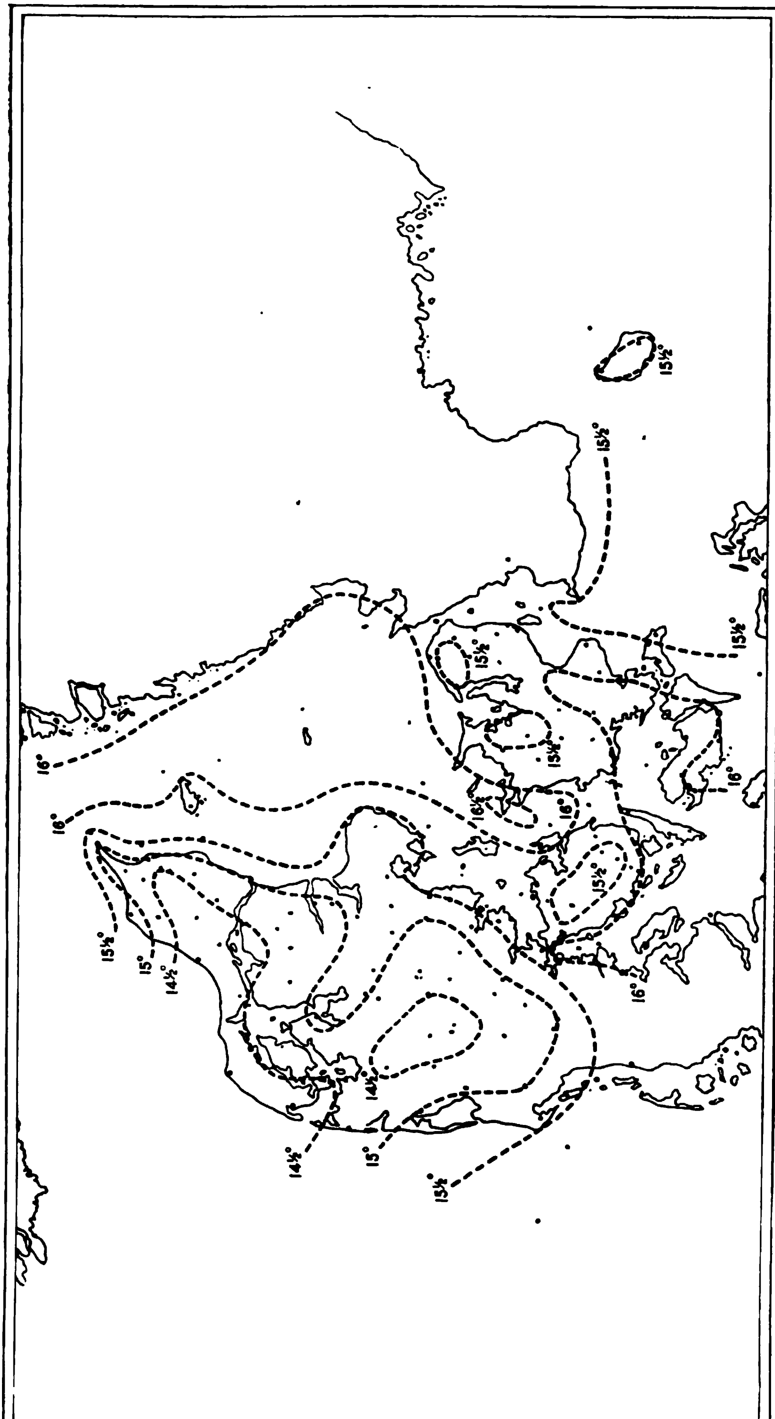

ISOHYETALS: NORMAL RAINFALL IN DENMARK, AUTUMN, 1861-1885. (PAULSEN.)



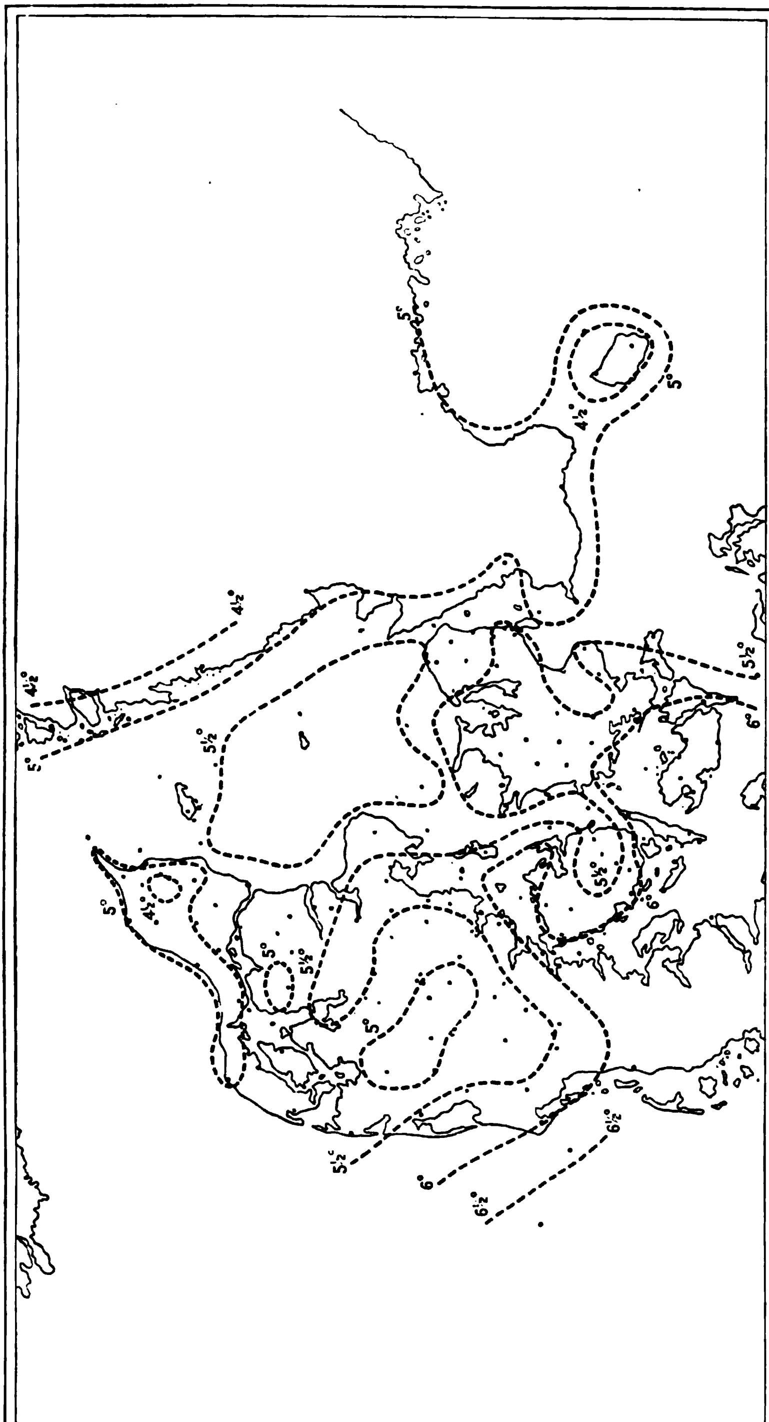

ISOHYETALS: NORMAL RAINFALL IN DENMARK, AUTUMN, 1861-1885. (PAULSEN.)



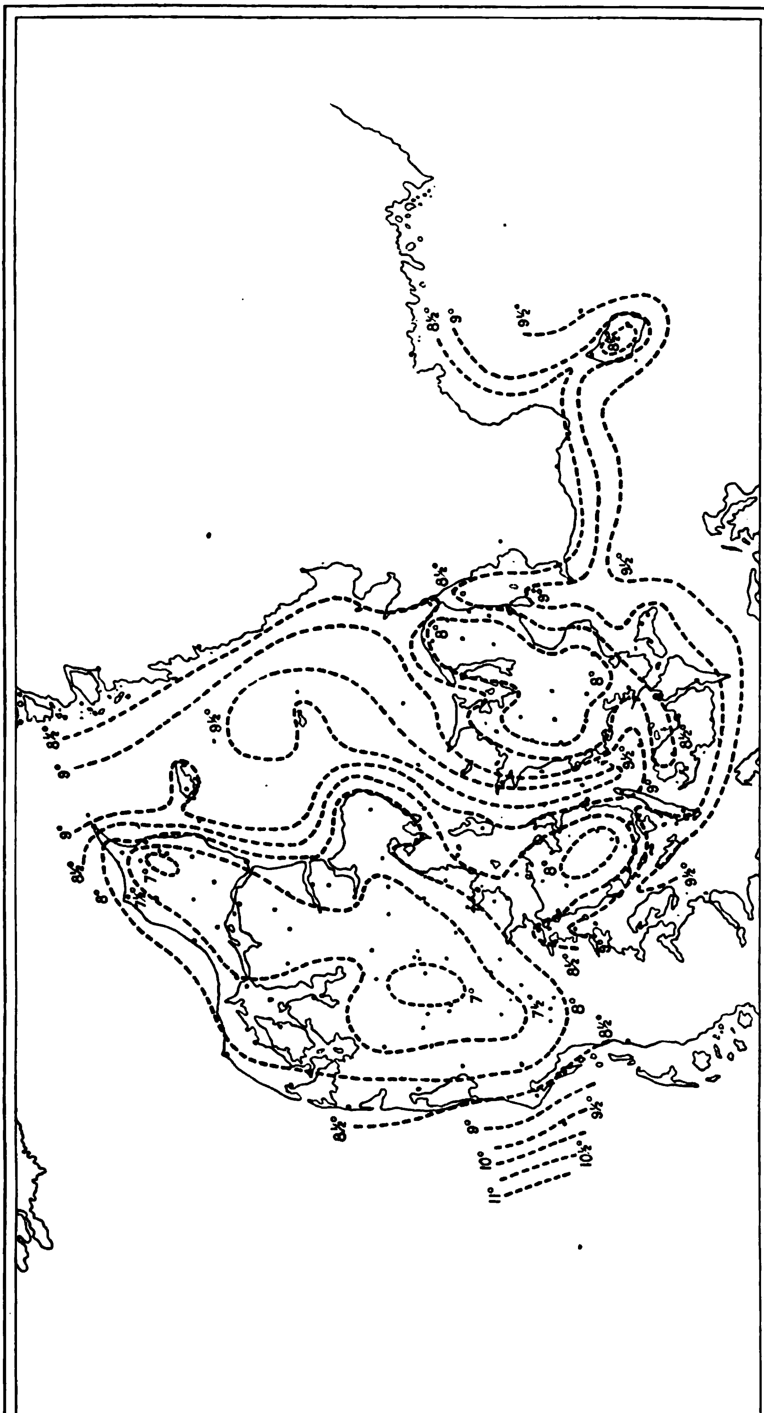

ISOHYETALS: NORMAL RAINFALL IN DENMARK, SPRING, 1861-1885. (PAULSEN.)




ISOTHERMALS: MEAN TEMPERATURE IN DENMARK, SUMMER. (PAULSEN.)




Isothermals: Mean Temperature in Denmark, Spring. (Paulsen.)



ISOTHERMALS: MEAN TEMPERATURE IN DENMARK, AUTUMN. (PAULSEN.)


ISOTHERMALS: MEAN TEMPERATURE IN DENMARK, WINTER. (PAULSEN.)

Thus the mean temperature of the country does not increase in winter from the north to the south, but, on the contrary, from the east to the west. In spring the distribution of the mean temperature is nearly the same as in winter. As the water in the Baltic at this season is about 2° colder than in the Kattegat, the higher temperature of the spring occurs latest in the island of Bornholm, the most eastern part of the country.

In summer the temperature immediately beyond the boundaries of the country is lowest over the Skagerrak, the sea between Norway and Jutland. We therefore find the lowest mean temperature in northwestern Jutland. Toward the south the higher temperature of the Continent makes its influence felt, and the temperature is, therefore, highest toward the south; but the vicinity of the Swedish province of Skaane causes Seeland to be much warmer than Funen. In autumn, when the water still preserves part of the heat which it has absorbed during the summer, the isotherms take, as in winter, a direction pretty nearly parallel with the coast. The warmest part of the country is, at this season, the island of Bornholm, in the Baltic, whereas the reverse is the case in the spring. The influence of the water in increasing the temperature shows itself also in the number of days when the temperature is below the freezing point. In the middle of Jutland there are, at this time of the year, twenty to twenty-five such days; on the coasts, on the contrary, only six to ten.

The distribution of the atmospheric pressure, which decreases toward the northwest, causes the southwest winds, coming from the Atlantic, to be, upon the whole, the more prevalent, and thus essentially to determine the Danish climatic conditions. During the cold season of the year they bring the mild and moist air of the ocean over the country, while during the warm season the comparative coolness of these winds counteracts the high temperature produced by the heating of the earth.

On this account Denmark has generally mild winters and comparatively cool summers; but as this country, with its surrounding large inland seas—the North Sea, the Kattegat, and the Baltic—is connected with the Continent it not infrequently happens that the influence of the Continent makes itself felt, and produces severe cold in winter and great heat in summer. Denmark presents, therefore, rather great contrasts in the climatic conditions of different years, and great variation is thus also characteristic of the Danish climate.

In the following remarks we shall further explain this by various tables of the most important climatic elements.

*The atmospheric pressure and the wind.*—The longest series of observations of the atmospheric pressure regularly recorded in Denmark are those made at Copenhagen, which, however, only date from 1838.

The table below gives a view of the mean height of the barometer at Copenhagen in the different months, and also of the highest and lowest

registered height and of the daily mean variation of the atmospheric pressure. The observations were made at the elevation of 13 meters above the surface of the sea. The correction for gravity and the reduction to sea level have not been applied.

*The atmospheric pressure (in millimeters) at Copenhagen.*

| Months. | Monthly mean. | Monthly mean (1838–1870). | | Absolute. | | Range in 24 hours. | |
|---|---|---|---|---|---|---|---|
| | | Maximum. | Minimum. | Maximum. | Minimum. | Mean. | Highest observed. |
| January | 759.2 | 770.2 | 749.3 | 785.2 (1858) | 717.4 (1863) | 5.2 | + 28.2 |
| February | 58.6 | 69.9 | 50.3 | 84.7 (1882) | 22.3 (1867) | 5.5 | — 35.9 |
| March | 57.9 | 65.9 | 46.5 | 84.0 (1880) | 21.2 (1858) | 5.3 | + 28.0 |
| April | 58.5 | 64.7 | 50.9 | 79.5 (1854) | 29.0 (1855) | 4.2 | — 21.9 |
| May | 59.3 | 62.7 | 55.6 | 76.2 (1866) | 31.2 (1861) | 3.4 | — 17.4 |
| June | 58.6 | 62.4 | 54.9 | 74.4 (1870) | 38.8 (1862) | 3.1 | — 13.8 |
| July | 57.7 | 62.6 | 52.5 | 71.5 (1863) | 39.8 (1844) | 2.9 | — 13.1 |
| August | 58.1 | 64.0 | 52.3 | 72.6 (1842) | 37.8 (1878) | 3.1 | — 14.0 |
| September | 59.3 | 66.3 | 52.9 | 77.8 (1865) | 33.3 (1874) | 3.8 | — 17.8 |
| October | 57.8 | 67.0 | 49.6 | 81.1 (1887) | 25.0 (1881) | 4.5 | + 24.8 |
| November | 57.7 | 67.4 | 50.8 | 81.5 (1859) | 25.4 (1854) | 5.3 | — 26.4 |
| December | 58.7 | 69.6 | 49.3 | 84.9 (1889) | 20.1 (1881) | 5.3 | + 32.7 |

Reduction to sea level, 1.2 millimeters. Correction for gravity, +0.7 millimeters.

The mean height of the barometer at Copenhagen is, thus, at 13 meters above the sea level, 758.5 millimeters. The difference in the mean atmospheric pressure in the various months is so trifling that the highest monthly mean is only 1.6 millimeters above the lowest. The yearly range of the pressure is therefore very small. This uniformity in the barometrical pressure must be ascribed to the situation of Denmark between sea and continent, where the yearly range of pressure is in contrary directions.

Notwithstanding this similarity in the monthly heights of the barometer, the table shows that the mean heights in the same months in the various years may deviate from each other in winter as much as 26 millimeters, in summer as much as 10 millimeters.

The height of the barometer is thus very unsteady, which also appears from the monthly mean variation in twenty-four hours, which in winter is more than 5 millimeters, while in the summer months it falls to 3 millimeters.

The table gives, further, a view of the greatest variation in the atmospheric pressure which has been observed in the course of twenty-four hours. Comparatively greater changes may, however, occur in a shorter time. The greatest change registered in one hour is 5 millimeters.

The atmospheric pressure decreases over Denmark from the south toward the north. At The Skaw, the most northern place in the country, the mean height of the barometer is 1.2 millimeters lower than in Copenhagen, and at the most southern station from which we have regular observations, the island of Bogó, the mean atmospheric pressure is 0.3 millimeter higher than in Copenhagen, which thus gives a difference of 1.5 millimeters between the northern and southern parts of Denmark.

On the other hand, the difference between the height of the barometer in Copenhagen and in the island of Fanoe, the most western part of the country, is only 0.1 millimeter, while the height of the barometer on the north coast at Bornholm is 0.4 millimeter greater than in Copenhagen. The lowest pressure is thus to the north of the country, and it is also the winds from southwest and west which predominate over the winds from all other directions.

According to the newest investigations regarding the wind conditions in Denmark, which have lately been made by Mr. Willaume-Jantzen, the mean direction of the wind over the whole country in the different seasons is as follows:

| | |
|---|---|
| Winter | S. 36° W. |
| Spring | S. 50° W. |
| Summer | S. 92° W. |
| Autumn | S. 46° W. |
| Year | S. 56° W. |

The mean direction of the wind is, however, not the same in the different parts of the country. At Haustholm, the most northwestern point of Jutland, it is S. 45° W. If we proceed from here to the southward along the west coast of Jutland, the direction becomes more westerly, so that at Tarm, nearly in the middle of the west coast, it is S. 55° W. If we go from Haustholm toward The Skaw, the wind is about due west, namely, S. 95° W.; and if we continue our way through the Kattegat to Copenhagen, the wind hauls constantly more from the west toward the south, so that it is S. 57° W. in Copenhagen. Further toward the east the mean direction is about the same as at Copenhagen, it being at Bornholm not more than 5° more southerly than at Copenhagen.

The reason for this change in the mean direction of the wind is to be found in the secondary depressions, which partly approach the coast of Jutland from the North Sea, and partly travel through the Skagerrak and the Kattegat, further to the east.

The force of the wind is, during the autumn and the winter, 4 (by Beaufort scale); during the other seasons, 3.

The western and northwestern winds are those which, in the most southern part of the country, blow with greatest force. At Gjedser, however, the east wind blows with as much force as the west.

The mean force of the various winds appears from the following table (Beaufort scale, 0–12):

| | | | |
|---|---|---|---|
| N | 3.1 | SW | 3.5 |
| NE | 3.4 | W | 3.9 |
| E | 3.2 | NW | 4.0 |
| S | 3.1 | | |

The number of storms is as follows:

| | |
|---|---|
| Winter | 12 |
| Spring | 7 |
| Summer | 5 |
| Autumn | 11 |

The number of cases in which the various winds get stormy, viz, in how many cases out of 100 each wind has the character of a gale, appears from the following table:

| | N. | NE. | E. | SE. | S. | SW. | W. | NW. |
|---|---|---|---|---|---|---|---|---|
| Winter | 9 | 12 | 13 | 10 | 10 | 10 | 15 | 14 |
| Spring | 4 | 6 | 5 | 3 | 3 | 4 | 7 | 7 |
| Summer | 3 | 3 | 2 | 1 | 2 | 5 | 11 | 9 |
| Autumn | 9 | 13 | 12 | 7 | 8 | 13 | 18 | 15 |
| Year | 6 | 9 | 8 | 5 | 6 | 8 | 13 | 11 |

The percentage of storms is thus greatest during winter and autumn, least during spring and summer. The table shows further that westerly and northwesterly winds at all seasons have the greatest storm percentage. Next to these winds the northeasterly and easterly winds are the most stormy during the winter, spring, and autumn. During the summer, on the contrary, the southwest wind is the most stormy next to the winds from northwest and west.

Actual hurricanes, in which the force of the wind has reached 40 meters per second, have not devastated Denmark.

A greater force of the wind than 35 meters has not been observed. About three-fourths of the storms do not last more than forty-eight hours, and the greatest part of the remainder not more than ninety-six hours. There are only a few examples of storms lasting for a very long time. The wind was stormy without interruption in the Kattegat for eleven and one-half days, viz, from the 28th of December, 1865, to the 8th of January, 1866.

*Temperature conditions.*—Although the climate of Denmark must be considered to be an insular climate with comparatively mild winters and cool summers, the contrast with the continental climate is yet far from being so great as, for instance, in the case of the climate of Scotland or the west coast of Norway. While thus the mean temperature of the winter in Copenhagen is 0.3° C. lower than at Edinburgh, the mean heat of the summer is 2° higher. On the other hand, the winter at Copenhagen is 4.2° C. warmer than at Riga and the summer 1° C. colder. In the direction from north to south Denmark is more influenced by the sea than southern Norway and northern Germany. The winter months at Stettin are thus 0.2° C. and at Christiania 4.2° C. colder than at Copenhagen, while the summer at Stettin is 1° C. warmer and at Christiania 0.3° C. colder than at Copenhagen.

The following table shows the monthly mean temperatures at the Agricultural School at Copenhagen for the period 1861 to 1890, as also the highest and lowest temperatures observed during this period:

| Month. | Mean temperature. | Monthly means. | | Absolute extremes. | |
|---|---|---|---|---|---|
| | | Maximum. | Minimum. | Maximum. | Minimum. |
| | ° C. | ° C. | ° C. | ° C. | ° C. |
| January | —0.3 | 3.4 | [1]—4.4 | 9.5 | [3]—18.6 |
| February | —0.4 | 3.0 | —4.7 | 10.8 | —25.0 |
| March | 1.0 | 5.0 | —3.2 | 16.5 | —18.5 |
| April | 5.6 | 7.7 | 2.8 | 22.5 | — 6.8 |
| May | 10.4 | 14.2 | 7.0 | 29.2 | — 3.6 |
| June | 15.0 | 19.4 | 12.7 | 32.5 | — 0.4 |
| July | 16.6 | 18.7 | 14.2 | 32.4 | 3.9 |
| August | 15.9 | 19.0 | 12.8 | 29.8 | 0.6 |
| September | 12.8 | 14.9 | 9.8 | 29.8 | — 3.2 |
| October | 8.0 | 10.6 | 5.4 | 20.8 | — 7.0 |
| November | 3.0 | 6.4 | 1.2 | 13.0 | —15.2 |
| December | 0.5 | 3.6 | —4.1 | [2]9.6 | —18.3 |

[1]—6.7° C. in 1893. [2]9.8° C. in 1891. [3]—23.2° C. in 1893.

| *Mean temperature.* | ° C. |
|---|---|
| Winter | —0.1 |
| Spring | 5.7 |
| Summer | 15.8 |
| Autumn | 8.1 |

The mean variation of the temperature from day to day for the various months ranges between 1.3° C. (in August and September) and 1.8° C. (in June).

The greatest differences which have been observed between the mean temperatures of two successive days are 10.8° C., in January, and 7.4° C., in March and October.

The accompanying charts (see plates XXXII–XXXV) give a view of the distribution of the temperature over the country in the various seasons.

It appears from these that the temperature of the inner part of the country is in all seasons colder than over the seas, even if the elevation above the sea be regarded.

As to the diurnal range of the temperature, the following table gives a view of the mean diurnal range in Copenhagen and in Herning, in the middle of Jutland:

| Month. | Copenhagen. | Herning. |
|---|---|---|
| | ° C. | ° C. |
| January | 1.3 | 1.9 |
| April | 5.1 | 6.4 |
| July | 5.4 | 7.0 |
| October | 2.6 | 4.0 |

In order to give an idea of the difference between the mean maximum and the mean minimum, we append the following table for this factor as being the mean for inland stations and coast stations:

| Month. | Inland stations. | | | Coast stations. | | |
|---|---|---|---|---|---|---|
| | Mean maximum. | Mean minimum. | Mean difference. | Mean maximum. | Mean minimum. | Mean difference. |
| | ° C. | ° C. | ° C. | ° C. | ° C. | ° C. |
| January | 1.1 | —3.4 | 4.5 | 1.5 | —2.4 | 3.9 |
| February | 1.9 | —3.0 | 4.9 | 1.7 | —2.1 | 3.8 |
| March | 4.6 | —1.8 | 6.4 | 3.8 | —1.0 | 4.8 |
| April | 9.7 | 1.1 | 8.6 | 8.8 | 2.3 | 6.5 |
| May | 14.8 | 4.3 | 10.5 | 13.7 | 6.1 | 7.6 |
| June | 20.2 | 9.4 | 10.8 | 18.6 | 10.7 | 7.9 |
| July | 21.7 | 11.3 | 10.4 | 20.2 | 12.7 | 7.5 |
| August | 21.8 | 11.8 | 10.0 | 20.1 | 12.8 | 7.3 |
| September | 16.9 | 8.8 | 8.1 | 16.4 | 10.4 | 6.0 |
| October | 10.8 | 4.5 | 6.3 | 10.9 | 6.0 | 4.9 |
| November | 5.1 | 0.2 | 4.9 | 5.8 | 1.8 | 4.0 |
| December | 1.5 | —3.0 | 4.5 | 2.2 | —1.5 | 3.7 |

In the preceding remarks we have mentioned that the principal characteristics of the conditions of temperature in Denmark are a consequence of its situation between a large sea to the west, which sea is in immediate connection with the Atlantic, a smaller inland sea to the east, and continents separated by narrow channels to the north and the south. That the conditions of temperature are really influenced by this situation of the country appears also from the heat, which is brought to the country by the various winds, as is shown by the thermal windrose below:

| Season. | N. | NE. | E. | SE. | S. | SW. | W. | NW. | Calm. |
|---|---|---|---|---|---|---|---|---|---|
| | ° C. | ° C. | ° C. | ° C. | ° C. | ° C. | ° C. | ° C. | ° C. |
| Winter | —3.3 | —3.4 | —1.7 | —0.4 | 0.8 | 1.8 | 1.7 | 0.3 | —0.9 |
| Spring | —1.3 | —1.5 | —0.3 | 0.6 | 1.2 | 1.1 | 0.4 | —0.2 | —1.4 |
| Summer | —0.1 | 0.8 | 1.3 | 1.7 | 1.1 | —0.4 | —1.2 | —1.1 | —1.0 |
| Autumn | —2.2 | —2.1 | —0.4 | 0.7 | 1.8 | 0.7 | —0.3 | —0.8 | —1.2 |

The warmest wind is in winter from the west and in spring from the south. In summer the country receives its greatest heat from the southeast, and in autumn the heat comes again from the south as in spring.

The point from which the coldest wind comes is in winter and spring in the northeast, in summer in the west, after which, in autumn, it is again to be found in the north. The difference between the mean temperature of the warmest and coldest wind is greatest in winter, viz, 5.2° C., and least in spring, viz, 2.4° C.

*Precipitation.*—The rainfall is greatest in the western part of the country, where the yearly mean is about 72 centimeters, decreases towards the east, and is in Copenhagen on the average 55 centimeters. This decrease in the rainfall in an easterly direction is, however, not regular. Although the country has no great hills, the influence of

elevation makes itself felt by more ample rainfall on the weather side of the hill ranges.

It is also worthy of observation that the Great Belt and the Kattegat are distinguished by their very slight rainfall.

The accompanying charts (see plates XXVIII-XXXI) give a view of the distribution of the rainfall in the different seasons. As appears from these, autumn is the most rainy season, spring the driest.

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## 7.—THE CLIMATE OF NORWAY.

Prof. H. MOHN.

*The temperature of the air.*—The coldest districts in Norway, where the mean temperature of the year is less than 32° F., are the highland tracts and the interior of Finmark (Karasjok, latitude 69° 17′, has 27°). At the seashore it is only on Varanger Fjord that the mean temperature for the year is less than 32°. The highest annual mean temperature is met with at Skudesnaes, on the west coast, latitude 59°, viz, 45.3°. The coast from the Romsdals Fjord to the Christiania Fjord has a mean temperature of 44°. The Lofoten Islands have 41° to 38°, and the North Cape 35.2°.

The interior of southern Norway and of Finmark has the longest winter—two hundred days with a temperature of less than 32°—and the lowest winter temperature, with the mean temperature of the coldest day less than 14°. From the interior of the country, as we approach the coast, the temperature becomes everywhere milder in winter. From Lindesnes, the southernmost promontory of Norway, we can trace a quite narrow belt along the west coast northward as far as the entrance to the Throndhjems Fjord, where the mean temperature of the coldest day is above 32°. Röst, the outermost point of the Lofoten Islands, also belongs to this portion (34° in January). The January isothermal line of 32° reaches the seventieth parallel of latitude off Tromsö. It passes, on the one side, down to the most southerly margin of Iceland, and on the other side over Denmark and Germany, down toward the Alps. In January the interior of Finmark has a mean temperature of 3.6°, and central Norway, at an elevation of 1,600 feet, has 11° to 12°. In the latter region, inversion of temperature—highest in higher levels—is a very frequent phenomenon. In general, the isothermal lines follow the outline of the coast, and lie very closely together.

The *summer* is hottest in the Östland (southeastern Norway). July in Christiania stands highest with 62.6°. Next to it comes Hardanger (July, 58.6°) and interior Sogn (60.6°). Karasjok, in the interior of Finmark, has in July a mean temperature of 54.5°. The summer is, upon the coast, colder than farther on in the interior of the country. It is coldest on the coast of Finmark (Vardö, July, 47.5°) and in the mountain regions (Böros, 2,000 feet, 52° in July). The temperature in July at the

North Cape (latitude 71°, 50°) is again met with on the southernmost part of Iceland (latitude 63° or 64°). The isotherm of 52° passes across Lofoten (latitude 58°) and Shetland (latitude 62°). The isotherm of 56° passes from the west coast (latitude 60°) right across the North Sea to the north of Scotland. If we reduce the temperature to the level of the sea, we obtain a maximum of heat for the month of July of upward of 62° in southeastern Norway.

As the interior of the country has warm summer and cold winter, and the coast cool summer and mild winter, the annual range of temperature becomes greatest in the interior of the country (51° in Finmark and 45° in central Norway) and least on the coast (only 18° on the outermost Romsdal coast). The range is about 27° along the entire coast from Lindesnes to Vardö.

In Österdalen and in the interior of Finmarken the mercury may freeze in cold winters.

On the outermost coast, from Romsdal to Joederen, the thermometer never falls below 12°, while in Karasjok −58° has been observed.

The highest temperatures have been observed in Christiania (93°) and in Finmark (96° on Varanger Fjord). Over a tract across the middle of the country, about the sixty-fifth parallel of latitude, the highest temperatures recorded do not attain to what has been observed in Östland and in Finmark. Along the entire coast 77° to 79° is attained, but upon the extreme outer fringe of rocks and islands barely 75°. The extreme lowest temperatures are chiefly observed in January, in some places in February or in December, and in a few places in March. The extreme highest temperatures are found in June or in July, and in some places in August.

The diurnal range of the temperature of the air is greatest in Östland (Christiania, 15° in July, and 3° in January), and least on the coast (only 5° in July). In Finmark it is not noticeable during the period of continuous night. At Vardö it is 5° in July.

In the spring the heat everywhere travels inland from the coast, in Finmark from north to south. In the autumn the cold travels seaward from the interior, in Finmark from south to north.

*The relative humidity* is greatest on the coast of Finmark (annual mean, 82 per cent). Leirdal, at the head of the Sognefjord, has only 65 per cent for the year. In winter the relative humidity is greatest in the cold interior (85 per cent) and least on the west coast (70 per cent). In the summer it is greatest on the coast (upwards of 80 per cent), and least in the interior of the country (Christiania, 60 per cent). On the driest days it may fall as low as 12 per cent.

*The pressure of the air.*—On the average of the year there is a maximum of pressure in southeastern Norway, and a minimum of pressure over the Norwegian Sea between Iceland and North Cape. In January central Norway has a maximum pressure of 29.97 inches (reduced to sea level and the latitude of 45°), and the North Cape has the lowest pres-

sure in Norway (29.63 in.). A minimum pressure appears to the east of Iceland (29.45 in.), and a still lower pressure (29.37 in.) to the west of Iceland, south of Greenland. In July there is a minimum of pressure (29.80 in.) over central Norway (latitude, 61°). Along the portion of the land that extends along the coast we meet in this month with a zone having a maximum atmospheric pressure of upward of 29.85 inches; and over the ocean between Iceland and Norway a trifling minimum of 29.76 inches.

*Wind.*—In consequence of this normal distribution of atmospheric pressure the prevailing winds of the winter blow off the land, curving to the right. They are land winds, and blow along the land, keeping it on the right, consequently northeasterly along the Skager Rack, southerly along the west coast, and southwesterly in northern Norway. They produce good sailing winds from Christiania to Vardö. They are, to a great extent, cold winds that cool the adjacent portion of the sea down to a lower degree than farther out in the open ocean. In summer the prevailing winds are sea winds. They blow along the land, keeping it on the left, especially in southern Norway, where the coast of the Skager Rack most frequently has southwesterly winds, Lindesnes westerly, and the west coast northerly winds. In northern Norway the prevailing summer winds are northerly. At that season of the year the prevailing winds therefore produce good sailing winds from the North Cape to Christiania.

In Christiania the prevailing wind in winter is northeast; in summer, south. In winter there is a maximum of pressure, in summer a minimum, to the north and west of Christiania.

Twice as many winds blow along the coast of Norway in one or other direction as blow across the coast from or toward the land in the same month.

*The force of the wind* is, on the coast, greater in winter than in summer. In winter it is rarely calm on the coast, but calms are very frequent in the interior of the country in the proximity of the maximum pressure. In summer it is relatively often calm on the coast, but less frequently calm in the interior. Generally speaking, the force of the winds on the coast is at all periods of the year much greater than it is in the interior.

*Storms* are most frequent on the coast (thirty storm days per annum) and rare in the interior (four storm days per annum). Their usual direction is the same as that of the prevailing winds, the average of the whole country being from southwest, and next frequently west and northwest. They are most frequent in winter, principally in December and January (four per month), and rarest in summer (barely one per month).

*The amount of cloud* is, upon the whole, considerable in Norway, especially on the coast. The coast of Finmark has the greatest amount of cloud, more than three cloudy days for each clear day. In

the interior the amount of cloud approaches to half clear. The summer months are somewhat clearer than the winter months. The number of perfectly clear days is greatest in the interior of the country, in the lowland regions, being on the average five per month. The number is least on the coast and in the more elevated tracts of the interior, where it falls to an average of a little more than three per month. The number of days in which the sky is entirely overcast is not quite evenly distributed over the country. The number is somewhat greater in the north than in the south, and varies from fifteen to eight per month. The winter months show, in most places, the greatest number of such days, having from seven to twenty-one, but usually between sixteen and eighteen.

*Precipitation.*—The number of days of rain or snow is, upon the whole, greatest on the coast from Jaderen to Vardö, and least in the Östland. At the North Cape in Lofoten and on the west coast between Stad and the Sognefjord, precipitation occurs as often as two hundred days per annum. On Dovre and in the Skager Rack the annual number of days with rain or snow is about one hundred. The coast has usually the greatest number of days of precipitation in January (18.2), but the interior, in the Östland, in July (14.8) and August. The fewest number of days of precipitation is everywhere in April (respectively 10 and 7). The number of hours of precipitation is least in the interior of the country (900 per annum), and increases towards the coast (1,890 per annum on the west coast). It is greatest in the colder and least in the warmer months, without, however, exactly following the variations of temperature. The Östland, the Skager Rack coast, and Lister have a maximum in November (90 to 120 hours per month), while Sœtersdalen, the west coast and its fjords, and the coast farther northward as far as Finmark have a maximum in January (100 to 260). In Finmark the maximum occurs nearer spring and autumn, partly, also, in July (about 100 hours per month). The minimum occurs in the Östland in May (53) and on the west coast in June (94).

The number of hours of precipitation on a day with rain or snow is least in the interior of the country and at Lister, and greatest in the fjord districts of the Province of Bergen. At Tönset, Öslerdalen, we have, on the average of the whole year, 4.7; on the Skager Rack, 8; at Mandal, 6.5; at Ullensvorng (Hardanger), Bergen, Balestrand (Sogn), and Nordfjord, 10 to 12; on the coast of Romsdal, 7 to 11; on the coast of Nordland, 5 to 8; in Finmark, upward of 7; and in eastern Finmark, upward of 10. The number of hours in which there is precipitation on a day with such, is greatest in the winter months (9 hours in the Östland, and 13 hours in the Bergen Fjord) and least in the summer months (respectively 5 to 6 and 8 to 9).

From Vardö to Andenes, on Dovre, and in the mountain regions, snow is more frequent than rain in the course of the year. Snow may fall during every month of the year on the stretch of coast between North Cape and Lofoten.

*Amount of precipitation.*—The fall of rain and snow is greatest on the coast between Cape Stad and the Sognefjord, where it amounts to 77 inches per annum. The coast has throughout a greater fall than the interior, where it is only 12 inches per annum. The annual and monthly amount of precipitation in the coastal regions is not evenly distributed, but exhibits several distinct maxima, one in Lofoten (60 inches per annum), one on the Nordland coast, between the Salton Fjord and the Ranen Fjord (42 in. per annum), one between Stad and the Sognefjord (77 in. per annum), and one just north of Christiania (45 in. per annum). On the west coast of southern Sweden there is also a maximum of upward of 30 inches per annum. An axial line drawn through these maxima represents the coastal maximum of precipitation and follows the coast in the same manner as the other lines for equal amount of temperature, pressure, force of vapor, etc.

The greatest rainfall occurs in the Östland in July to September, but on the west coast later in the autumn or in the beginning of winter. The spring months have the least amount of rain or snow.

The amount of precipitation on a day with such is, on the average of the year, unmistakably least in the interior of the country, about 0.15 inch, and increases as we approach the coast, where it is, on the average, 0.26 inch. In the Östland the largest daily rainfall occurs in July and August (0.21 in. per day), on the Skager Rack coast in September, and on the west coast in the autumn months. The Bergen fjord shows a maximum in the winter months (November, 0.42 in. per diem). The least fall on a rainy or snowy day occurs, in most places, in April.

The intensity of precipitation, measured by its amount during one hour of precipitation, is least for the whole year in the interior of the country (Röros, 0.013 in.; Karasjok, 0.014 in.), and increases as we approach the coast (Mandal, 0.069 in.; Florö, 0.041 in.). It is greatest in the summer months, except in the Bergen fjords (December), and least in April; earlier in a few places.

*Fogs* are most frequent on the west coast and the coast of Finmark in summer, and least so in winter. In the Östland that relation is reversed. During winter we meet with frosty fogs in the innermost heads of the fjords, when the frost is severe and the cold winds blow from the land down upon the open fjords.

*Thunderstorms* are not very frequent in Norway. Taking the average of the whole country, 5.4 thunderstorms occur per annum (5.7 in the interior and 5 on the coast). The largest numbers occur in the Östland and on the west coast (7 per annum), and the least number on the coast of Finmark (0.7 per annum). By far the largest number of thunderstorms occur in summer, especially in July and August (in the Östland 2 to 3 per month, on the west coast 1 to 2 per month).

Thunderstorms in winter are almost unknown in the Östland, but, on the other hand, they occur on the west coast with a certain degree of frequency, especially in mild weather in January (up to 0.4 per

month). These winter thunderstorms accompany gales of wind from southwest, west, and northwest, and are dangerous, as the thunder clouds float near the earth at that season. One hundred Norwegian churches have, during the last one hundred and fifty years, been struck by lightning and destroyed, and of that number not fewer than 40 have been destroyed by the thunderstorms of winter on the west coast, as far north as Lofoten. At the North Cape, also, thunderstorms occur in winter.

*Snow line.*—Where the surface of the country, with its plateau, rises high above the sea level, and the precipitation during the greater part of the year is in the shape of snow, there are extended snow fields, from which glaciers descend to the adjoining valleys. The limit of perpetual snow is estimated at 3,080 feet on Seiland (near Hammerfest); 5,150 feet on Dovrefjeld; 4,100 to 4,900 feet on the Jotun Mountains; 3,100 to 4,100 feet on Justedals-Brae; and 3,100 to 4,100 feet on Folgefon

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## 8.—THE DEVELOPMENT OF CLIMATOLOGY IN THE GERMAN EMPIRE.

Dr. Hugo Meyer.

In the German Empire there is very considerable material on hand, collected during many years of continued observations, and if the comprehensive descriptions of the climate of Germany have not in more recent times kept pace with the increase of valuable data of observations, it is because the quantity of material offered to the professional meteorologists in recent years by the great central institutes has assumed such proportions as to be almost unmanageable. A thorough revision of this material would be very desirable, but it would require the consecration of the whole of a man's working power for a very long time to accomplish this. It would be impossible for me to offer a general survey of the climate of Germany, based upon the older works, because these works have long been known and, therefore, I should be giving nothing new.

I shall, instead of this, present a short communication on the development of climatology in my fatherland during the last two decades. The progress that has been made during this time is apparent to all, but opinions as to the objects of climatology have so radically changed that it may well be worth while to group these aspirations together and to show how far the efforts to realize them have been crowned with success. It is well known that climatological investigations have always been carried on with extraordinary zeal and great success in Germany, and the leading ideas have often originated with us. I hope to demonstrate that the present joins hands worthily with this glorious past.

When we consider that in Germany, in spite of the limited extent of its area, there is such a number of meteorological services in full

activity, we might suppose that that unity and homogeneity so essential to climatological research might be wanting in the observations that are made in so many different localities. Luckily this is not the case, although very little is heard of conferences of the directors of the various services. The international meteorological congresses, particularly those of Vienna and Rome, with the meetings of the international committees attached to them, have alone almost sufficed to create uniformity. As the individual services independently supported the resolutions of these congresses and meetings as far as possible, the uniformity in the observations naturally resulted. This favorable result encourages me to express here the wish that those systems of meteorological observation that have not yet followed the recommendations of the international conferences may now no longer delay, and especially not for the reason that their neighbors have not taken the step. Germany, with its numerous systems of stations, has well shown the great utility of a close adherence to the recommendations of the international conferences. All the German central establishments work independently, one of the other, and still when we compare their publications they agree perfectly among themselves as regards contents and are now all on the same level.

Let us next consider the compilation and discussion of the observations made at the stations by the central offices.

The choice of the places where meteorological stations should be established has been made with great care, according to the views expressed by Koeppen. (*Tageblatt der 59 Versammlung deutscher Naturforscher und Aerzte zu Magdeburg*, 1884, p. 74.) Stations of the second order—there is still a great want of stations of the first order, particularly in south Germany—should be, whenever practicable, located in public buildings (schools and other institutions of learning) in order that they may be kept as long as possible in the same position.

The same care as that taken in the choice of the place is exercised in the equipment of the stations. Only such instruments as have beforehand been thoroughly tested are furnished to the stations, and as complete uniformity as possible in the instruments is more and more striven for. In regard to the efforts to determine the kind of exposure best suited to our climate, I recommend reference to the works of Koeppen: *Studien über die Bestimmung der Lufttemperatur und des Luftdruckes* (Archiv d. deutschen Seewarte, X, Hamburg, 1888); Sprung, *Bericht über vergleichende Beobachtungen an verschiedenen Thermometeraufstellungen zu Gr. Lichterfelde bei Berlin* (Abhandlungen d. k. preuss. meteorol. Instituts, Bd. I, No. 2, Berlin, 1890), and Hellmann, *Bericht über vergleichende Beobachtungen an Regenmessern verschiedener Konstruction zu Gr. Lichterfelde bei Berlin* (ibidem, No. 3, Berlin, 1890), as also *Resultate des Regenmess-Versuchfeldes bei Berlin, 1885–1891* (Meteorol. Zeitschr., Bd. IX, p. 173, 1892).

In proportion as these precautions assure the excellence and com

parability of the observations, so we have striven to preserve these qualities by frequent inspections. Indeed, the value of a regular visitation of the stations has long been recognized (in Prussia such visits of inspection have been a part of the program ever since the establishment of the institutions), but for a long time it was not possible to carry out to a desirable extent the plans necessary for its accomplishment—that is, it only became possible on a satisfactory scale when in the establishment of a new or the reorganization of the existing Institute the necessary funds were subscribed by the state.

The checking of the tables of observations compiled at the central offices is only a necessary complement to the inspection of the stations themselves. In this respect, also, great progress has been made within the past decade. There is now indeed no German meteorological central office which has not at its disposal the necessary means for this purpose, and if the computing and graphic supervision of the tables are not everywhere carried out according to the same methods, still it may be relied upon that no notable errors slip in anywhere.

In the publication of the observations German institutions adhere most strictly to the plan of the international committee, and the number of the meteorological stations whose observations are published *in extenso* as second order stations has in Germany gradually become very considerable (1876, 17; 1891, 61).

To the *Deutsche Seewarte* is due the credit of having made accessible the results of the observations of the German ships upon every ocean, as well as the various non-European stations (Labrador and the German colonies) in distant lands. In addition to the publication of observations, most of the central stations issue also special works, which are either written by their members or are compiled from material contained in their archives, and are frequently of a climatological nature. These works find a place in special sections of the German meteorological annuals (Kingdom of Bavaria and Kingdom of Saxony), or they are published in special journals (*Archiv d. Deutschen Seewarte*, *Abhandlungen des Kgl. Preussischen Met. Instituts*).

If we compare the amount of work incumbent upon these central institutes with the number of their personnel and reflect that they are charged with still other duties—such, for instance, as predictions of the weather and the supervision of the rain stations, which are more of a hydraulic and technical nature, and the supervision of thunderstorm stations—we shall then better comprehend why the collation and deduction of the chief results for the places at which the observations are published *in extenso* makes but very slow progress. And when by a resolution of the international conference of the representatives of the meteorological services of all countries in Munich, in 1891, the directors of the central offices, above all, were requested to have published, from time to time, tables of the climates of their respective countries, computed according to the most accurate methods available and for as

many stations as possible, this resolution was certainly everywhere greeted with joy; but whether, within a reasonable time, it will lead to any practical results, at least for the greater part of Germany, must, unfortunately, be seriously doubted. At any rate, it would be most regrettable if any diminution in the extent of the work now done should take place. Still, I hope that in view of the critical thought which distinguishes all the German central offices, this danger is not great. The data offered to the general public for more extended study must, above all, be reliable, since the public outside of the central stations will not always be in a position to estimate the reliability of the individual stations.

In order, however, to facilitate as much as possible the formation of independent judgments by distant investigators, the Prussian Meteorological Institute has for some years set the example of giving in every volume of the Meteorological Year Book, for a certain number of second-order stations, a short history of the observations and a description of the situation of the station. This seems to me to be a substantial progress, and it is very gratifying to see that other German central stations have already followed this example.

I have before remarked that the central bureaus of Germany were all entirely independent of each other a few years ago—however, without injury from this independence, which is, on the whole, certainly advantageous. A uniformity in certain respects has been introduced, namely, since 1887 the results of the observations, formerly compiled separately by each institute, have been issued under the common title, "German Meteorological Year Book," and the part published by the "Seewarte" contains a complete index of all the different sections of the Year Book.

This may be considered the most substantial progress which has been accomplished in German climatology by the meteorological central institutes. The principal result is, that the investigations carried on throughout the Empire are made available to the most remote districts in a detailed, convenient form, and with a full guaranty of their reliability. It has already been shown that there is still room for future development in this direction; in the meantime, however, we can confidently point to the German publications referred to as standards worthy of imitation.

We have still briefly to refer to the advance that has been made in climatology through the study of the published investigations, and particularly by private individuals.

It can not be ignored that climatological work has been considerably advanced by the publication *in extenso* of the observations made at the numerous stations, and even if at first the work done was almost entirely confined to the old ground, and if with climatological sketches of particular places there also came forth papers which treated special questions extending over large regions, still these were distinguished

for the strict criticism which was bestowed on the material used, in particular that of previous years. The methods of checking and reduction previously worked out by Hann, Wild, and Hellmann have here also found zealous adherents, and even now scarcely any German climatological work dare appear in which the authority is not given for the material used and the method by which it has been tested.

The conventional methods for the discussion of meteorological observations have also been subjected to serious criticism. Kremser first pointed out how unsatisfactory was the presentation of the cloudiness by the arithmetical mean values. In the other climatic elements it is, however, more or less the same. I believe that I may, myself, lay claim to having shown in my "Guide to the Discussion of Meteorological Observations for Climatology" (*Anleitung zur Bearbeitung Meteorologischer Beobachtungen für die Klimatologie.* Berlin, T. Springer, 1891) how few climatological factors harmonize with the opinion—until now almost universally prevailing, and which is to be found even in the best textbooks and compendiums—that the arithmetical mean value is that which occurs most frequently among those observed and is also the most probable among those to be looked for. I accentuated the importance of the study of the curves of frequency—that is to say, the curves showing the frequency of an observation as a function of its total amount—in the study of climate, and proposed to introduce the most frequent values in conjunction with the arithmetical means—that is to say, the *Scheitel* values or those values which belong to the summits of the curves of frequency, and which are, therefore, the most frequent or the most likely observations. The fact that a few months after the publication of my *Anleitung* the question as to the advisability of introducing the most frequent values into the climatological tables came up for discussion on the motion of Mr. Rotch, at the Munich Conference, shows that criticism of the importance of mean values must have already begun in other quarters and that it was only granted to me to forestall others in bringing it forward. I will, however, not omit to mention here (compare page 14 of my *Anleitung*) that similar curves for atmospheric pressures were published in "Meteorological Charts for the Ocean District adjacent to the Cape of Good Hope," by the Meteorological Council, as early as 1882, and that, according to a communication made by Professor Harrington at the Munich Conference, the "curves of frequency" must frequently have been drawn in America also. As these investigations were hitherto unknown to me, I can not give any further details concerning them, and, besides, the subject is scarcely admissible within the limits of this paper.

The most frequent values and the curves of frequency have already been considered in some of the newest German publications, and the hope that they will receive more and more attention will certainly not be disappointed, since the Munich Conference has recommended the further extension of the system of frequency values.

Finally, it remains still to be mentioned that the long-neglected non-periodic changes of the climatic elements and the tendency to preserve the weather conditions now receive more attention. The ideas so graphically developed by Koeppen have guided these investigations, and it may be anticipated that in the near future many of the numerous gaps in our knowledge will be filled up.

This is not the place to enter into details. I have only endeavored to present some of the principal points of view which have become important in the development of German climatology, and it will bring joy to my heart if my native land is not refused the acknowledgment that she is at the present time showing herself worthy of her past.

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Dr. J. Hann.

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*Hann, J.* Ueber die monatlichen und jährlichen Temperaturschwankungen in Oesterreich-Ungarn. Sitzungsb. Akad. Wien, lxxxiv (Part II), 1881, pp. 965-1037.

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*III.—Precipitation.*

*Sonklar, Carl v.* Grundzüge einer Hyetographie des Oesterreichischen Kaiserstaates. (Mit einer Regenkarte von Oesterreich.) Mitth. der k. k. geogr. Ges., Wien, iv, 1860, pp. 205-238, 1 ch.

*Sonklar, Carl v.* Regenkarte der Oesterr.-Ungarischen Monarchie. Vertheilung der Niederschlagshöhen im Jahresmittel. Wien (Ed. Hölzel), 1881.

*Hann, J.* Untersuchungen über die Regenverhältnisse von Oesterreich-Ungarn. I. Theil. Die jährliche Periode der Niederschläge. Sitzungsb. Akad. Wien, lxxx (Part II), 1879, pp. 571-635. II. Theil. Veränderlichkeit der Monats- und Jahresmengen; gleichzeitige Vertheilung der letzteren in der Periode 1849-1878. Sitzungsb. Akad. Wien, lxxxi (Part II), 1880, pp. 45-79.

*Schenzl, Guido.* Ueber die Niederschlagsverhältnisse in den Ländern der ungarischen Krone. Publikation der kgl. ung. met. Central-Anstalt. Budapest, 1885. Fol., 35 pp., 1 ch.

*IV.—Winds.*

These have not yet been collected together into a separate publication. A general description, however, may be found in:

*Supan, Alex.* Statistik der unteren Luftströmungen. Leipzig, 1881. 8°. 296 pp., 1 pl.

*V.—Cloudiness.*

*Elfert, Paul.* Die Bewölkung in Mittel-Europa mit Einschluss der Karpathienländer. Petermann's geogr. Mittheilungen, Gotha, 1890, pp. 137-148, 1 ch.

*Elfert, Paul.* Die Bewölkungsverhältnisse von Mittel-Europa. Halle, 1885. 8°. 97 pp., 5 ch.

Climatic monographs relating to many places in Austria-Hungary, with tabular data of all climatic elements, may be found in *Zeitschrift der Oesterr. Gesellschaft für Meteorologie*, Vienna, Vols. I-XX, 1866-1885, and in *Meteorologische Zeitschrift*, Vienna and Berlin, Vols. I-X, 1884-1893.

## 10.—METEOROLOGY OF THE ITALIAN MOUNTAINS.

By P. FRANCESCO DENZA.

Italy enjoys the advantage of being able to explore a stratum of atmosphere both denser and higher than that in any other region of Europe, since its territory rises from the level of the sea to the greatest altitudes that are reached in Europe, such as are found in the chains of Alps that bear the name of Pennine Alps.

Anyone acquainted with our mountains, and especially with the Italian Alps, must admit that it would be most difficult, if not impossible, to establish upon them stations fulfilling the conditions that are required for a perfect meteorological mountain station, i. e., that it should be located upon an isolated peak and manned by observers able to attend, throughout the entire year, continuously to the study of meteorology.

Not only the summits, but also many of the passes of our various chains of Alps are difficult of access even in good weather; in winter access to them is absolutely impracticable and it is impossible to live upon them. One such trial was made by those patient observers who, at the initiative of Signor Dollfuss, remained during the entire year, from August, 1865, to August, 1866, on the Theodule pass (between Piedmont, Italy, and Valais, Switzerland), at 3,330 meters above the sea, thus giving the only series in all Europe of regular observations made seven times a day at so remarkable a height for an entire year; a feat that had never before been accomplished. Although this station was located on one of the passes more sheltered from our severe cold, and not on an isolated peak, nevertheless those brave mountaineers suffered more or less, and one of them contracted a malady which brought him to the grave.

Since I have always been in communication with the observers at our mountain stations, I have known full well the sufferings to which those brave soldiers of science were exposed and their great self-sacrifice in living at such elevated regions during the winter. The observers at Valdobbia, Little St. Bernard, and Stelvio have frequently lived almost entirely buried in snow, exposed to great cold and to violent gales.

In the Maritime Alps, where the great chain descends and begins little by little to merge into the Apennines, perhaps it would not be difficult to find a suitable point, as, for example, the "Mount of the Sette Pani," which has a free horizon from the Gulf of Liguria on one side and the valley of the Po on the other. But this station, although most important for the climatological details of our country, in my opinion would not be of great importance for general meteorology in view of all the special conditions that surround it; moreover, its altitude is not very great.

In the Apennines we have some points suitable for high stations, but not as many as could be used with profit. The great Sasso of Italy

(2,909 meters), the culminating point of the entire chain, offers an interesting excursion in fine weather; it is not possible to live there in winter; and, in any case, it would be an arduous task to construct, on that peak, a well-sheltered edifice for regular observations.

On the other hand, this would not be very difficult on Mount Cimone, which is 2,167 meters above the sea, in the Apennines of Emilia. This peak is isolated, is well exposed to the influences of both the Mediterranean and the Adriatic, and affords an extensive view over a large tract of country; neither is access to it very difficult. For some time the founding of an observatory on such a peak has been contemplated, through the initiative, in the first place, of Signor Parenti, a fellow of the Italian Alpine Club; afterwards with the cooperation of branches of the same club in Florence, in Enza, and in Modena, but this was a serious undertaking and private funds were inadequate; therefore, the Government assisted in the execution, and it is hoped that the work will be accomplished before long.

Another important point in our Apennines is Mount Cavo, in Lazio. As is well known, the objection of the illustrious Père Secchi, in No. 10, Volume XV, of the "Bollettino Meteorologico del Collegio Romano," is that this mount is nearly in the same topographical position as that of the Puy de Dôme, in France, although the altitude may be notably less. Mount Cavo stands at 966 meters and the Puy de Dôme at 1,463 meters above sea level, but both are at nearly the same elevation above the neighboring plateau.

The observatory of Monte Cassino, in the Province of Terra di Lavoro, is also placed in a good location in the southern Apennines, but the altitude is not great, being only 527 meters.

Nevertheless, the meteorological station which our society has established at Monteleone, in Calabria, is quite important for the study of the atmospheric movements over the center of the peninsula, and still more important is the other station which has been located at no great distance from the first, in the mountains of Tiriolo. Indeed, both of these stations, but especially the latter, are found upon the central crest of the Apennines and dominate the two seas, the Ionian and the Tyrrhenian; they constitute two most appropriate stations for observing atmospheric currents advancing from the south over the Mediterranean toward Italy, and then over the rest of Europe.

The two observatories of Vesuvius and Etna (the first of which has from the beginning been under the direction of Prof. Luigi Palmieri and the second under the care of Prof. Pietro Tacchini) are also (and especially the second on account of its altitude of 2,990 meters) very important. But in my judgment (and persons well versed in meteorology have also expressed the same opinion) these two stations would accomplish more if they devoted themselves to terrestrial physics rather than to pure meteorology, both because of the influence which the neighboring volcanoes exercise over them and because they are not free on every side, as the volcanic cones rise above both of them.

Two other important stations were located on the Bay of Naples, one on the summit of the hill near the town of Camaldole, where it commands not only Naples, but also all the Phlegraian Fields and surrounding region, and nearly the entire Terra di Lavoro, the other upon the height (called "Deserto") above Sorrento, which is like an advanced post from which the Bays of Naples and Salerno are overlooked.

Having considered all the great difficulties of finding points in our mountains isolated and entirely free from outside influences, care had to be taken to find other places at unusual heights which, although not satisfying all the conditions desirable for a perfect international station, would, nevertheless, furnish data most useful to general meteorology.

Furthermore, there is no doubt that from the observations made continuously and regularly at these high stations, one ought to be able to deduce important results concerning the march of atmospheric pressure, the influence which mountains exert as obstacles to the advance of storms, and also concerning the distribution and variation of temperature and of hydrometers of every kind. As to the lower winds only, it would not be possible to obtain reliable observations from places so surrounded by higher mountain crests; but the observations of the upper winds would be valuable.

Is it not then to be concluded that if it were possible to establish meteorological posts on some of our isolated Alpine peaks, it would then be certain that the indications of the instruments at these stations would be satisfactory, and as such be useful to general meteorology in an absolute sense?

Let us take, for example, in our Alps the principal peaks, Monviso, Rocciamelone, Gran Paradiso, Crivola, Cervino, etc.; will they be exempt from the influence of lower and neighboring mountains? Will they not feel the disturbing action of the snow that covers them as well as that of the rocks of which they are formed?

Here I agree with Dr. Julius Hann, director of the Central Meteorological Office of Vienna, who was so much interested in this question at the time of the Meteorological Congress at Rome;[1] and with him I affirm that for certain elements stations similar to these would be suitable; for other elements, such as temperature, they would give large differences.

Therefore, considering the impossibility of doing any better, it is necessary to devise methods for procuring meteorological observations in the more elevated strata of the atmosphere.

With this object we have arranged in regular order the different States that contain mountains on which meteorological stations are established under the best conditions possible. If the localities are not really bad, if the observations are made properly and continuously for

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[1] Bericht erstattet den zweiten internationalen Meteorologen Congress über die Beobachtungen auf hohen Bergen und in Luftballons. (Punkt 30 des Programms) von J. Hann, 1879.

many years, the value of such points of observation is incontestable.[1] The discussion of the meteorological data thus obtained will certainly give results important to science, as Plantamour has so beautifully demonstrated by comparing the observations made for a long time on the Great St. Bernard with those made at Geneva. This is also shown by other meteorologists who have occupied themselves with these studies, and it will also be confirmed by the Italian observations when data for a sufficient number of years shall have been collected.

I pass on now to describe briefly what has been done in Italy for mountain meteorology.

Previous to the year 1865, there did not exist a single station in all Italy having an elevation greater than 1,000 meters above the level of the sea at which regular meteorological observations were made. The first of this kind was established in that year at Cogne, in the Graian Alps, through the efforts of the abbot, Pietro Carrel. Since that time, by the effectual cooperation of the Italian Alpine Club and of many organizations, as well as of generous individuals, and with the aid of the Government, the number of elevated stations in the Alps has greatly increased. In the year 1873 such stations began to be established, also, upon the Apennines, always through the initiative of our Alpine Club.

At present we have twenty-one stations at an elevation of more than 1,000 meters above the level of the sea, seventeen of which are on the Alps, and four on the Apennines. Among the former there are only four at an elevation of over 2,000 meters, including the Great St. Bernard, which is common to Italy and Switzerland. To the seventeen other stations may be added fifteen whose altitude is a little less than 1,000 and more than 800 meters. The history of these stations, and especially of those elevated more than 1,000 meters above the sea, I have set forth in various publications.[2]

In each of the various groups of our Alps we have sought to occupy the highest points where we could find habitable places, and volunteers able to make observations.

In the Lepontine Alps, the higher passes are occupied by Switzerland, which country maintains the stations of St. Gothard, Splugen, and Simplon; we were, therefore, not able to go higher. However,

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[1] Bericht erstattet den zweiten internationalen Meteorologen Congress über die Beobachtungen auf hohen Bergen und in Luftballons. (Punkt 30 des Programms) von J. Hann, 1879.

[2] "Il Commodoro M. F. Maury, e la Corrispondenza delle Alpi, e degli Appennini Italiani, 1875," published in "La Corrispondenza meteorologica Italiana Alpina-Appennina."

Relazione del P. Francesco Denza a S. E. il Ministro di Agricoltura, Industria e Commercio, 1877, published in "La Corrispondenza meteorologica Italiana Alpina-Appennina."

Relazione del P. Francesco Denza, al Presidente del Club-Alpino, Italiano," published in 1878 in the "Bollettino del Club Alpino, Italiano," and afterwards in the "Bollettino meteorologico del R. Osservatorio di Moncalieri." Volume XIII.

thanks to the initiative of the Valtelline branch of the Italian Alpine Club and to the concurrence of the Government, we have not far from Spluga established a meteorological post on the Italian side which is at very nearly the same height as that located on the Swiss side, close to the barracks of the Italian custom-house.

I note, moreover, that through the kindness of the Director of the Meteorological Service of Switzerland (Dr. Rudolph Wolf, of Zurich), the two stations St. Gothard and Simplon transmit to us, also, their observations as promptly as does the old station of the Great St. Bernard.

In the Maritime Alps, also, we have not ascended much higher. But this group is relatively lower than the other, and besides the more elevated places and passes are not under our control. Nevertheless, thanks to the cooperation of the engineer, Pesso, we have succeeded in establishing two stations for temperature and rainfall at Tenda and at Limone, on the southern and northern sides of Mount Tenda, of which the respective altitudes are 1,006 and 819 meters.

I give here the names of the mountain stations having an elevation of more than 800 meters above the level of the sea, arranged according to the groups into which our mountains are naturally divided.

| Station. | Altitude. |
|---|---|
| I. ALPINE. | |
| Carnic Alps: | *Meters.* |
| Sauris | 1,218 |
| Cavalese | 985 |
| Auronzo | 871 |
| Coredo | 830 |
| Asiago | 995 |
| Rhaetian Alps: | |
| Stelvio | 2,543 |
| Bormio | 1,340 |
| Vilminore | 1,013 |
| Collio | 929 |
| Varese | 862 |
| Lepontine Alps: Spluga | 1,904 |
| Pennine Alps: | |
| Collé di Valdobbia | 2,548 |
| Mottarone | 1,468 |
| Courmayeur | 1,220 |
| Aropa | 1,175 |
| Valchiusella | 1,100 |
| S. Giovanni—Andorno | 1,024 |
| Graglia | 841 |
| Graian Alps: | |
| Piccolo S. Bernardo | 2,160 |
| Moncernsio | 1,930 |
| Ceresole Reale | 1,620 |
| I. ALPINE—Continued. | |
| Graian Alps—Continued. | *Meters.* |
| Cogne | 1,513 |
| Balme d'Ala | 1,470 |
| Cottian Alps: | |
| Ceresole | 1,390 |
| Castel del fino | 1,310 |
| Sampeyre | 979 |
| Saira S. Michele | 961 |
| II. APENNINE. | |
| Northern: Monte Benna | 1,340 |
| Central: | |
| Casmaldoli | 1,121 |
| Alvernea | 1,116 |
| Monte Caro | 965 |
| Vallombrosa | 954 |
| Southern: | |
| Monte Vergine | 1,377 |
| Tiriolo | 849 |
| Caggiano | 829 |
| Potenza | 826 |
| Agnone | 806 |

Inasmuch as the general interest in meteorology did not really begin in Italy until after the year 1865, and more definitely in the year 1870, I am thus able to demonstrate that this important branch of meteorology, viz, the study of the atmosphere at mountain stations, is not neglected by us.

In order that the meteorological researches on the atmosphere at unusual elevations may give the best results, it is necessary to maintain other stations located a little lower down, but near at hand.

Therefore, we are trying to provide each one of the three more elevated stations, Stelvio, Mount Valdobbia, and Little St. Bernard, with other meteorological posts lower down and at no great distance therefrom.

The station Bormio is situated on the slope of Stelvio. Not far away from Little St. Bernard are the two stations Cogne and Ceresole Reale, and at the foot of Mount Valdobbia the station Riva will be established before long. These stations are a little less than half the height of their more elevated neighbors.

Besides these there are other stations not distant from those just mentioned, and still lower down, which serve better to reveal the laws to which the meteorological elements are subject at strata of different altitudes.

Indeed, for Stelvio, besides the station Bormio, in the depths of Valtellina, there is now established another still lower at Sondria, in the heart of that valley, and by means of the station at Como, the elevated observatory of Stelvio is sufficiently well coordinated with that of Milan in the plain of Lombardy.

For Mount Valdobbia, we have both Varallo in the center of the adjacent valley of Valsesia and Novara, at the opening of the latter.

For Little St. Bernard, we find Aosta in the middle of the valley of the Dora Baltea, Chatillon, where this turns southward, and Ivrea, at the entrance of this valley. Aosta also controls Mount Valdobbia because it is situated between the two passes of Little St. Bernard and of Valdobbia at almost the same distance from each.

Between the stations Ivrea and Novara there is the beautiful group of the Biellese stations, viz, Graglia, Oropa, S. Giovanni, d'Andorno, and Biella.

In the plain Vercelli serves as a point of union between Ivrea, Biella, and Novara.

I give here the series of stations associated with each of our three highest meteorological posts.

Stelvio serves as a control for the mountain stations in this portion of Switzerland, and the Tyrol and Little St. Bernard for the similar stations in Savoy.

| Group. | Altitude. | Group. | Altitude. |
|---|---|---|---|
| STELVIO. | *Meters.* | LITTLE ST. BERNARD—continued. | *Meters.* |
| Stelvio | 2,543 | Cogne | 1,543 |
| Bormio | 1,340 | Aosta | 608 |
| Sondrio | 363 | Chatillon | 532 |
| Como | 212 | Ivrea | 239 |
| Milan | 147 | Vercelli | 150 |
| VALDOBBIA. | | INTERMEDIATE, BETWEEN VALDOBBIA AND LITTLE ST. BERNARD. | |
| Valdobbia | 2,548 | Aropa | 1,175 |
| Riva | 1,138 | S. Giovanni | 1,029 |
| Varallo | 466 | Graglia | 841 |
| Novara | 168 | Biella | 434 |
| Vercelli | 150 | | |
| LITTLE ST. BERNARD. | | | |
| Little St. Bernard | 2,160 | | |

Similar control, although in a less degree, is attained in the case of the two more elevated stations already established upon the Apennines. For, on the side of the hill Penna, there is Bedonia, at 548 meters above the sea, and in the plain we find Parma at 66 meters. Similarly, not far from Alvernia, Arezzo is situated, at an elevation of 272 meters, and a little lower down, Florence, at an elevation of 76 meters.

As complementary to this historical account, I will give here the mean results of the meteorological observations carried on at our more elevated stations, Stelvio, Mount Valdobbia, and Little St. Bernard, contrasted with those of the respective lower stations, Bormio, Varallo, and Cogne.

At Mount Valdobbia, Little St. Bernard, at Cogne, and at Varallo, the observations were begun at the end of 1871; at Stelvio they commenced in 1873, at Bormio in 1876.[1]

The values which are here given refer, consequently, to the period 1871–1888, for the first-named stations; for Stelvio from 1873 to 1888, and for Bormio from 1876 to 1888.

The following tables contain the monthly means, for the periods above mentioned, of the atmospheric pressure, the temperature, and the relative humidity in percentages. Moreover, the absolute maximum and minimum of the barometer and the thermometer for each month of the whole period, and, finally, the mean monthly amounts of rain and of snow which fell at each station. Thus an approximate idea of the climate of our elevated mountain stations is obtainable.

In the year 1876 I published a large volume giving the observations continued for five years, from 1871 to 1875, at five meteorological stations situated in the valley of Aosta, namely, Great St. Bernard, Little St. Bernard, Cogne, Aosta, and Ivrea. The geographical positions and the heights above the level of the sea for these five stations are as follows:

*Meteorological stations in the valley of Aosta.*

| Station. | North latitude. | Longitude west of Rome. | | Altitude. |
|---|---|---|---|---|
| | ° ′ | ° ′ | h. m. | *Meters.* |
| Great St. Bernard | 45 50 | 5 23 | 0 22 | 2,478 |
| Aosta | 45 44 | 5 20 | 0 21 | 587 |
| Little St. Bernard | 45 40 | 5 33 | 0 22 | 2,160 |
| Cogne | 45 37 | 5 7 | 0 20 | 1,543 |
| Ivrea | 45 28 | 4 36 | 0 18 | 289 |

The seasonal means of temperature for the stations are:

| Station. | Winter. | Spring. | Summer. | Autumn. |
|---|---|---|---|---|
| | ° C. | ° C. | ° C. | ° C. |
| Great St. Bernard | —8.1 | — 2.3 | + 7.0 | +0.2 |
| Little St. Bernard | —6.1 | — 0.6 | 10.0 | 2.3 |
| Cogne | —4.1 | + 4.6 | 14.8 | 5.6 |
| Aosta | —0.2 | 11.6 | 20.0 | 11.0 |
| Ivrea | +2.5 | 12.7 | 22.4 | 13.3 |

[1] At Stelvio, Valdobbia, and the Great St. Bernard the meteorological observations were taken six times a day, every three hours from 6 a. m. to 6 p. m. At the other stations three times, namely, 9 a. m., 3 and 9 p. m.

Now, since these stations lend themselves sufficiently well to a comparative study, because all are situated in the same basin between the latitude of 45° 28′ (Ivrea) and 45° 50′ (Great St. Bernard), and because the elevations are included between 289 meters (Ivrea) and 2,478 meters (Great St. Bernard), therefore, I shall endeavor to determine the variation of the temperature with altitude.

From a discussion of the thermal observations obtained from these five stations there result the following means:

| Season. | Mean variation. | |
|---|---|---|
| | Per 100 meters. | Per 1° C. |
| | ° C. | Meters. |
| Winter | 0.53 | 189 |
| Spring | .62 | 161 |
| Summer | .76 | 132 |
| Autumn | .63 | 152 |
| Year | 0.63 | 159 |

These results have been fully confirmed by similar work done in the Signal Office of the United States of America.[1] In his annual reports for successive years, the Director of this Office, General Hazen, published some results of the observations taken at the highest meteorological station in the world, upon Pikes Peak, during a space of five years, from November, 1873, to June, 1879, comparing them with the observations made at two other neighboring but lower stations, viz, Colorado Springs and Denver.

The positions of these three stations are:

| Station. | Altitude (meters). | Latitude. | Longitude (Greenwich). |
|---|---|---|---|
| | | ° ′ | ° ′ |
| Pikes Peak | 4,313 | N. 38 48 | W. 104 59 |
| Colorado Springs | 1,825 | 38 55 | 104 58 |
| Denver City | 1,606 | 39 45 | 105 04 |

From this data the following values result:

| Season. | Variation of temperature. | |
|---|---|---|
| | Per 100 meters. | Per 1° C. |
| | °C. | Meters. |
| Winter | 0.54 | 185 |
| Spring | .71 | 141 |
| Summer | .69 | 145 |
| Autumn | .58 | 172 |
| Year | 0.63 | 159 |

[1] Einige Resultate der meteorologischen Beobactungen auf dem Gipfel von Pikes Peak. (Zeitschrift der osterreichischen Gesellschaft fur Meteorologie, XVIII, 1883.)

The differences between these values and those which I obtained from the valley of Aosta are:

| Season. | Italy — America. | |
|---|---|---|
| | Per 100 meters. | Per 1°C. |
| | *Meters.* | °*C.* |
| Winter | —0.01 | + 4 |
| Spring | — .09 | +20 |
| Summer | + .07 | —13 |
| Autumn | + .05 | —13 |
| Year | 0.00 | 0 |

The agreement is really remarkable, taking into consideration the diversity of the regions in which the observations were made. From this result it may be inferred that the mean diminution of the temperature with altitude, as found in the Italian Alps, for a mean elevation of about 2,200 meters (from 289 to 2,478 meters) coincides with that in the mountains of North America for a mean elevation of about 2,700 meters (from 1,606 to 4,313 meters). So that it would be possible to admit that in these two regions the diminution of temperature between the altitudes 200 and 4,300 meters is in general about 1° C. for each 159 meters of elevation. The influence of the two seasons, spring and summer, is reversed in the American mountains and in our Alps. This, however, happens also in Italy, in the latitudes less than 45°, such as those of the American stations above referred to.

These results are quite satisfactory and are valuable for the hypsometry of our mountains, since they confirm a most important principle upon which rests the formula connecting the ratio between the diminution of temperature and the increase of altitude. Moreover, they give weight to other hypotheses that have recently been based upon that principle. It would be difficult to find elsewhere conditions more favorable for such study than those which occur in the region of Valdostana, where five points of observation are established within a very short distance and at the most diverse altitudes that it is possible to obtain among the high ones in our mountains. Among all the observatories, the Great St. Bernard alone exceeds Valdobbia and Stelvio in altitude and even surpasses these by but very little.

## MOUNT VALDOBBIA.

| Months. | Barometer. | | | | | Thermometer. | | | | | Humidity, mean quantity. | Rain, mean quantity. | Snow, mean quantity. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Maximum. | | Minimum. | | | Maximum. | | Minimum. | | | | |
| | Mean. | Value. | Year. | Value. | Year. | Mean. | Value. | Year. | Value. | Year. | | | |
| | *Met.* | *Met.* | | *Met.* | | °*C.* | °*C.* | | °*C.* | | *Cm.* | *Mm.* | *Mm.* |
| December, 1871–87 | 558.8 | 575.8 | 1881 | 539.2 | 1874 | —6.7 | 6.7 | 1883 | —20.7 | 1887 | 75.0 | 0.0 | 1,062.0 |
| January, 1872–88 | 561.0 | 577.4 | 1882 | 540.1 | 1873 | —7.0 | 3.3 | 1884 | —21.8 | 1888 | 70.3 | 6.0 | 1,011.5 |
| February, 1872–88 | 559.8 | 574.4 | 1873 | 537.1 | 1879 | —6.5 | 5.4 | 1883 | —20.7 | 1887 | 68.1 | 0.4 | 890.7 |
| March, 1872–88 | 558.9 | 574.4 | 1883 | 543.1 | 1886 | —3.9 | 11.6 | 1883 | —20.6 | 1883 | 70.3 | 0.0 | 1,104.6 |
| April, 1872–88 | 559.1 | 570.8 | 1886 | 540.2 | 1884 | —1.5 | 8.9 | 1872 | —14.2 | 1887 | 73.8 | 0.0 | 1,927.5 |
| May, 1872–88 | 562.4 | 574.0 | 1882 | 548.5 | 1885 | —0.1 | 18.0 | 1883 | — 8.9 | 1872–83 | 71.6 | 11.9 | 1,020.5 |
| June, 1872–88 | 565.5 | 575.8 | 1874 | 551.4 | 1881 | 5.8 | 15.5 | 1874 | — 5.3 | 1882 | 71.6 | 82.1 | 341.3 |
| July, 1872–88 | 567.6 | 575.7 | 1881 | 557.4 | 1888 | 9.4 | 25.7 | 1885 | — 0.9 | 1878 | 71.6 | 71.2 | 16.1 |
| August, 1872–88 | 567.3 | 575.9 | 1875 | 555.0 | 1876 | 9.3 | 19.2 | 1876 | — 2.7 | 1884 | 71.0 | 61.7 | 0.0 |
| September, 1872–88 | 566.0 | 575.4 | 1872 | 551.2 | 1887 | 5.7 | 16.8 | 1872 | — 7.4 | 1882 | 74.3 | 56.9 | 181.5 |
| October, 1872–88 | 563.0 | 574.2 | 1888 | 541.6 | 1875 | 0.8 | 13.6 | 1876 | —13.1 | 1887 | 73.6 | 16.1 | 1,023.7 |
| November, 1872–88 | 560.3 | 574.1 | 1881 | 544.7 | 1879 | —4.2 | 6.4 | 1881 | —16.2 | 1874 | 73.1 | 3.1 | 1,011.3 |
| Mean | 562.5 | 577.4 | 1882 | 537.1 | 1879 | 0.1 | 25.7 | 1885 | —25.8 | 1888 | 72.0 | 25.8 | 799.3 |

## VARALLO.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| December, 1871–87 | 720.8 | 737.6 | 1879 | 697.6 | 1884 | 1.7 | 14.4 | 1880 | —10.2 | 1879 | 81.1 | 82.5 | 49.4 |
| January, 1872–88 | 723.3 | 742.7 | 1882 | 699.0 | 1873 | 1.3 | 11.9 | 1882 | — 9.0 | 1880 | 82.7 | 47.0 | 76.0 |
| February, 1872–88 | 722.0 | 739.0 | 1882 | 693.5 | 1879 | 8.4 | 18.3 | 1877 | — 7.1 | 1887 | 77.2 | 37.5 | 212.6 |
| March, 1872–88 | 719.3 | 734.8 | {1879–80, 1887} | 700.1 | 1888 | 6.5 | 21.0 | 1881 | — 6.9 | 1883 | 73.2 | 91.1 | 33.2 |
| April, 1872–88 | 717.7 | 732.4 | 1886 | 701.6 | 1874 | 10.7 | 25.0 | 1874 | — 0.2 | 1878 | 71.3 | 191.5 | 0.0 |
| May, 1872–88 | 719.9 | 730.9 | 1881 | 705.6 | 1885 | 14.6 | 28.6 | 1882 | 2.8 | 1883 | 73.7 | 181.9 | 0.0 |
| June, 1872–88 | 721.4 | 731.8 | 1874 | 706.3 | 1881 | 18.7 | 30.9 | 1885 | 5.0 | 1873 | 69.3 | 159.8 | 0.0 |
| July, 1872–88 | 721.7 | 730.1 | 1881 | 711.2 | 1877 | 21.3 | 33.5 | 1881 | 7.4 | 1879 | 67.9 | 113.1 | 0.0 |
| August, 1872–88 | 721.5 | 729.5 | 1875 | 708.2 | 1876 | 21.2 | 31.7 | 1879–81 | 1.8 | 1887 | 70.4 | 163.4 | 0.0 |
| September, 1872–88 | 722.2 | 732.5 | 1888 | 707.9 | 1887 | 17.0 | 30.1 | 1879 | 4.5 | 1877 | 77.0 | 151.0 | 0.0 |
| October, 1872–88 | 721.5 | 735.3 | 1888 | 697.2 | 1875 | 11.4 | 22.6 | 1876 | 0.0 | 1878–87 | 79.4 | 179.0 | 0.0 |
| November, 1872–88 | 720.6 | 735.0 | 1880 | 703.2 | 1880 | 5.5 | 17.9 | 1881 | — 5.8 | 1876 | 78.8 | 125.2 | 37.2 |
| Mean | 721.0 | 742.7 | 1882 | 693.5 | 1879 | 11.1 | 33.5 | 1881 | —10.2 | 1879 | 75.2 | 126.9 | 34.0 |

## STELVIO.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| December, 1873–87 | 558.6 | 575.6 | 1880 | 539.7 | 1874 | — 9.0 | 10.3 | 1880 | —27.2 | 1887 | 69.4 | 75.6 | 699.1 |
| January, 1874–88 | 560.5 | 577.0 | 1881 | 541.5 | 1886 | — 9.2 | 3.4 | 1883 | —28.6 | 1888 | 69.1 | 55.2 | 568.6 |
| February, 1874–88 | 559.6 | 578.3 | 1882 | 537.2 | 1879 | — 8.5 | 0.8 | 1876 | —27.9 | 1888 | 76.0 | 62.6 | 768.8 |
| March, 1874–88 | 558.1 | 573.4 | 1882 | 540.8 | 1883 | — 6.8 | 6.6 | 1881 | —25.3 | 1888 | 74.6 | 90.5 | 659.6 |
| April, 1874–88 | 558.6 | 570.2 | 1886 | 546.6 | 1874 | — 2.4 | 8.3 | 1880 | —25.3 | 1882 | 76.6 | 117.1 | 926.6 |
| May, 1874–88 | 562.2 | 578.5 | 1878 | 548.9 | 1885 | 0.5 | 15.3 | 1882 | —18.1 | 1882–83 | 73.7 | 116.5 | 733.8 |
| June, 1874–88 | 565.4 | 575.0 | 1874 | 549.8 | 1881 | 5.0 | 15.9 | 1881 | —14.2 | 1881 | 69.6 | 114.8 | 214.5 |
| July, 1874–88 | 566.8 | 574.9 | 1874–81 | 557.6 | 1888 | 7.3 | 20.1 | 1881 | — 8.4 | 1882 | 68.1 | 132.1 | 93.5 |
| August, 1874–88 | 566.5 | 575.4 | 1875 | 554.5 | 1876 | 7.4 | 18.5 | 1877–79 | — 8.9 | 1882 | 71.2 | 114.7 | 78.5 |
| September, 1874–88 | 564.1 | 574.0 | 1885 | 538.5 | 1883 | 4.5 | 17.9 | 1879 | —11.8 | 1882 | 74.4 | 99.5 | 183.3 |
| October, 1874–88 | 560.3 | 573.7 | 1888 | 542.8 | 1875 | — 0.6 | 13.9 | 1876 | —19.6 | 1881 | 74.0 | 76.3 | 533.3 |
| November, 1874–88 | 559.0 | 573.8 | 1880 | 544.2 | 1879 | — 5.0 | 1.5 | 1878 | —21.9 | 1876 | 69.2 | 429.6 | 3,775.7 |
| Mean | 561.6 | 578.3 | 1882 | 537.2 | 1879 | — 1.4 | 20.1 | 1881 | —28.6 | 1888 | 72.2 | 123.4 | 769.6 |

## BORMIO.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| December, 1876–87 | 646.7 | 663.1 | 1879 | 627.1 | 1884 | — 0.7 | 13.5 | 1883 | —15.0 | 1879 | 72.6 | 52.2 | 286.7 |
| January, 1877–88 | 648.8 | 667.0 | 1882 | 630.0 | 1886 | — 1.1 | 12.2 | 1883 | —15.0 | 1888 | 70.7 | 16.3 | 159.1 |
| February, 1877–88 | 649.2 | 662.0 | 1887 | 624.7 | 1879 | 0.8 | 12.2 | 1878 | —14.0 | 1888 | 69.1 | 46.8 | 253.6 |
| March, 1877–88 | 645.3 | 660.0 | 1882 | 620.2 | 1878 | 0.9 | 16.9 | 1882 | —11.5 | {1878, 1883} | 70.7 | 89.1 | 335.3 |
| April, 1877–88 | 645.0 | 658.2 | 1886 | 632.0 | 1877 | 5.5 | 17.0 | 1880 | — 6.0 | 1888 | 71.8 | 44.6 | 54.0 |
| May, 1877–88 | 648.6 | 658.7 | 1881 | 634.4 | 1885 | 9.5 | 26.7 | 1882 | — 4.0 | 1887 | 68.9 | 84.6 | 18.5 |
| June, 1877–88 | 650.9 | 657.9 | 1877 | 636.8 | 1881 | 13.3 | 27.1 | 1877 | — 6.6 | 1885 | 67.9 | 75.1 | 0.0 |
| July, 1877–88 | 651.4 | 658.6 | 1881 | 642.7 | 1879 | 15.7 | 29.2 | 1881 | 5.0 | 1879–84 | 68.0 | 90.3 | 0.0 |
| August, 1877–88 | 651.1 | 658.5 | 1888 | 642.5 | 1880 | 15.4 | 27.3 | 1888 | 1.3 | 1879 | 70.2 | 77.6 | 0.0 |
| September, 1877–88 | 650.0 | 659.9 | 1884 | 638.4 | 1883–87 | 11.7 | 24.8 | 1879 | 1.6 | 1887 | 73.9 | 94.1 | 0.5 |
| October, 1877–88 | 649.3 | 661.6 | 1888 | 622.6 | 1886 | 6.4 | 19.4 | 1886 | — 4.2 | 1884 | 67.4 | 68.6 | 21.1 |
| November, 1877–88 | 647.9 | 659.8 | 1881 | 629.9 | 1886 | 1.6 | 15.3 | 1885 | — 9.0 | 1882 | 74.7 | 59.5 | 285.3 |
| Mean | 648.7 | 667.0 | 1882 | 620.2 | 1878 | 6.6 | 29.2 | 1881 | —15.0 | 1879–88 | 70.5 | 61.6 | 117.8 |

LITTLE ST. BERNARD.

| Months. | Barometer. | | | | | Thermometer. | | | | | Humidity, mean quantity. | Rain, mean quantity. | Snow, mean quantity. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Maximum. | | Minimum. | | | Maximum. | | Minimum. | | | | |
| | Mean. | Value. | Year. | Value. | Year. | Mean. | Value. | Year. | Value. | Year. | | | |
| | Met. | Met. | | Met. | | °C. | °C. | | °C. | | Cm. | Mm. | Mm. |
| December, 1871–87 | 583.2 | 598.8 | 1881 | 564.4 | 1874 | — 9.3 | 12.5 | 1876 | —25.8 | 1871 | 52.9 | 8.2 | 2,121.0 |
| January, 1872–88 | 585.3 | 597.2 | 1887 | 564.0 | 1873 | — 8.3 | 5.0 | 1874 | —26.0 | 1887 | 45.5 | 34.0 | 1,742.9 |
| February, 1872–88 | 582.9 | 599.4 | 1882 | 562.5 | 1878 | — 7.7 | 7.9 | 1876 | —25.2 | 1886 | 49.1 | 5.1 | 1,706.0 |
| March, 1872–88 | 582.8 | 587.2 | 1881 | 563.6 | 1882 | — 4.6 | 12.0 | 1875 | —21.8 | 1886 | 48.1 | 19.7 | 1,923.2 |
| April, 1872–88 | 582.0 | 593.9 | 1885 | 568.0 | 1877 | — 1.4 | 18.4 | 1874 | —15.8 | 1886 | 56.7 | 3.2 | 1,553.7 |
| May, 1872–88 | 585.8 | 596.2 | 1881 | 573.3 | 1874 | 2.5 | 21.8 | 1875 | —12.3 | 1878 | 60.6 | 110.8 | 724.8 |
| June, 1872–88 | 588.7 | 598.3 | 1874 | 574.9 | 1880 | 6.7 | 22.6 | 1875 | —11.9 | 1882 | 63.0 | 195.3 | 201.4 |
| July, 1872–88 | 590.4 | 597.7 | 1873–80 | 579.7 | 1881 | 9.4 | 25.0 | 1875 | — 6.0 | 1887 | 60.4 | 193.9 | 56.8 |
| August, 1872–88 | 587.8 | 597.9 | 1887 | 580.0 | 1878 | 9.0 | 25.0 | 1880 | — 4.8 | 1873 | 63.9 | 168.0 | 32.6 |
| September, 1872–88 | 589.2 | 597.8 | 1872 | 574.7 | 1886 | 5.8 | 19.7 | 1878 | — 7.4 | 1884 | 65.7 | 163.5 | 497.8 |
| October, 1872–88 | 585.8 | 597.8 | 1887 | 551.7 | 1885 | 0.5 | 19.0 | 1875 | —15.0 | 1886 | 62.9 | 75.2 | 682.7 |
| November, 1872–88 | 583.9 | 596.6 | 1881 | 570.0 | 1879 | — 5.1 | 9.5 | 1879 | —18.4 | 1876 | 54.0 | 61.3 | 1,291.2 |
| Mean | 585.7 | 599.4 | 1882 | 551.7 | 1885 | — 0.2 | 25.0 | 1875–80 | —26.0 | 1887 | 56.9 | 86.6 | 1,052.8 |

COGNE.

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| December, 1871–87 | 631.3 | 648.1 | 1879 | 611.0 | 1884 | — 4.6 | 11.5 | 1878 | —20.5 | 1871 | 58.4 | 34.0 | 515.1 |
| January, 1872–88 | 633.4 | 650.9 | 1881 | 611.4 | 1873 | — 4.3 | 9.0 | 1874–82 | —17.5 | 1878 | 53.6 | 35.4 | 574.6 |
| February, 1872–88 | 632.2 | 647.3 | 1873 | 608.5 | 1878 | — 3.2 | 9.0 | 1876–81 | —16.8 | 1885 | 54.0 | 26.2 | 381.1 |
| March, 1872–88 | 630.5 | 645.0 | 1881 | 611.2 | 1882 | — 0.4 | 14.0 | 1874 | —15.1 | 1885 | 54.5 | 41.0 | 356.4 |
| April, 1872–88 | 629.9 | 643.4 | 1885 | 615.9 | 1877 | 3.8 | 18.5 | 1874 | —11.4 | 1878 | 56.0 | 93.8 | 501.7 |
| May, 1872–88 | 632.8 | 643.8 | 1881 | 620.0 | 1884 | 8.3 | 21.5 | 1875–81 | — 4.0 | 1878 | 50.2 | 72.9 | 44.6 |
| June, 1872–88 | 635.1 | 645.5 | 1874 | 620.9 | 1880 | 12.9 | 24.5 | 1874–75 | — 0.8 | 1873 | 50.3 | 68.2 | 12.4 |
| July, 1872–88 | 636.5 | 643.6 | 1880 | 627.2 | 1887 | 15.5 | 28.0 | 1880 | 2.4 | 1878 | 51.0 | 50.5 | 0.0 |
| August, 1872–88 | 636.3 | 644.5 | 1887 | 625.3 | 1875 | 14.7 | 26.0 | 1877 | 8.0 | 1883 | 51.3 | 49.5 | 0.0 |
| September, 1872–88 | 636.0 | 644.9 | 1872 | 621.7 | 1886 | 10.9 | 23.0 | 1878 | — 2.0 | 1872 | 56.7 | 51.7 | 21.8 |
| October, 1872–88 | 633.8 | 646.6 | 1887 | 610.5 | 1875 | 5.0 | 19.6 | 1875 | — 9.0 | 1878 | 62.9 | 106.6 | 76.7 |
| November, 1872–88 | 632.2 | 644.5 | 1884 | 615.9 | 1879 | — 0.7 | 13.5 | 1881 | —14.0 | 1874 | 61.8 | 59.9 | 363.8 |
| Mean | 633.3 | 648.1 | 1879 | 608.5 | 1878 | 4.8 | 28.0 | 1808 | —20.5 | 1871 | 55.1 | 57.5 | 237.8 |

## 11.—THE CLIMATE OF THE MALAY ARCHIPELAGO.

Dr. J. P. Van der Stok.

1. *Observations.*—(A) A magnetic and meteorological observatory of the first order is established at Batavia. Hourly personal observations are being made here of barometric pressure, the shade temperature of the air, dry and wet bulb thermometer, rainfall, radiation thermometer, cloudiness of the sky, and of the three magnetic elements by means of a set of magnetometers of the Wild-Edelmann pattern.

Self-registering instruments are in working order, giving continuous curves of wind direction and velocity (anemometer, Munro), rain (Beckley's rain gauge), duration of sunshine (Jordan's patent), atmospheric electricity (Mascart's electrometer), radiation (Richard), and of the three elements of terrestrial magnetism (magnetograph, Adie). A large standard barometer to be read by means of a cathetometer, whose scale is controlled by a standard meter compared by the Paris committee, insures a reliable determination of the absolute height of the barometer at any moment and of the instrumental errors of newly purchased instruments. Weekly determinations of the absolute values

of declination, horizontal force, and inclination are made with a view to reducing the records of the magnetometers to absolute measure. The observatory is provided with a small telescope, used for observation of sun spots, of which a diary is kept, and with all kinds of optical instruments. The observations, reduced to absolute values, are published in extenso in annuals, the volume containing the observations made during one year being issued in the course of the next year. The eye observations of meteorological instruments commence January, 1866, an uninterrupted series of thirty-two years being now accomplished. The series of complete magnetical observations commences in 1884.

The results of those observations being given in Volume XIII of the series, reference to the contents of this volume and to the other volumes to be found in most of the large libraries in the United States may be allowed.

The staff consists of a director and a subdirector, a European computer, and 10 native computers, who also do the observational part of the work, which they do very well if once well trained to it.

(B) Throughout the Indian Archipelago, 194 stations, where observations of rainfall are being made, are kept in working order, the results being published in a separate publication, Rainfall in the East Indian Archipelago. For the greater number of these stations average values extending over fourteen years are available. The observers are surgeons of the army, civil medical officers, and private persons.

(C) At about 40 places in the Archipelago observations of the direction of the wind are being made by all classes of officials and private persons. These observations bear a private character and are published in the Annals of the Royal Physical Society.

(D) On board of Her Majesty's warships observations of wind direction and velocity, of temperature, and of rain, are being made daily at three fixed hours, and the records sent up to the observatory by the marine department.

(E) Extracts from the journals of Her Majesty's war ships from 1830 up to the present time have been made, and charts showing the direction of wind and ocean currents are in preparation.

(F) Observations of tidal waves and currents, partly made by means of self-registering tide gauges and partly by keepers of light-houses, are sent to the observatory, with a view to the computation of the constants after the methods of the harmonic analysis.

(G) A magnetic survey was made in the years 1874–1877 by Dr. G. von Ryckevorsel. The results of this survey are published in the Transactions of the Royal Academy of Amsterdam. The redetermination of the magnetic curves would be a very interesting subject of research, in all respects recommendable to private persons who desire to visit foreign countries and to combine scientific work therewith, or to scientific societies having at their disposal funds sufficient for such investigations.

2. *Climate.*—The climate of the Eastern Archipelago, taken as a whole, might be defined as a consequence of four preponderant influences, viz, the influence of the large Continent of Asia, the smaller influence of the Australian Continent, that of the southeast trade winds, and that of the northeast trade winds. The influence of the latter, however, is very small and only perceptible in the rarely frequented northeastern parts.

These influences are mixed up in various ways in different parts of the Archipelago, but the climate at all places bears the following general character:

1. There is no connection between the weather and the barometric pressure as observed in loco, the monsoons being the consequence of the annual oscillation of barometric pressure above the Asian and Australian continents; the observed barometric variations are due to diurnal inequality, local influences (of rainfall, etc.), and to movements of long duration, but do not constitute any material for tide prediction.

2. The temperature at all places on the coast is practically the same and oscillates between 66° and 96° F. The climate is essentially a sea climate, therefore neither excessive cold nor excessive heat occurs, and differences of temperature in different months are due more to an unequal distribution of rainfall throughout the year than to the consequences of the sun's varying position. The definition of the word "climate" being the meteorology of a region with special respect to living beings, it is not superfluous to state that the influence of the high temperature is not generally felt about midday, but rather during the afternoon when the sun has set and the sea breeze ceases blowing, while the land breeze, which, as a rule, is very feeble, is not yet perceptible. For the same reason the heat is considered oppressive, not in July and August, when the records are the highest, but during the months of April and November, when, owing to the changing of the monsoons, the velocity of the wind attains its minimum value.

As to the character of the monsoons in different parts of the Archipelago, it seems convenient to assume four different types:

1. The British Indian type to be observed in the northern part of Sumatra; maximum of rainfall in August, with southwesterly winds and fine season in February, the wind blowing from the northeast. In the northern parts of Borneo something like this monsoon is felt, but in a rather uncertain and undecided way.

2. Another type is to be found at places near the equator. Here no well-defined monsoons or wet and dry seasons can be stated. Rainfall occurs pretty constantly throughout the whole year.

3. A third and well-defined type is observed in the southern part of the China Sea, in the Java Sea, and, further eastward, all over the large and small Sunda Isles. In Java the southeast trade winds blowing along the west coast of Australia (and even more so in the eastern isles the dry winds blowing out from the Australian desert) cause a dry

season from May to September, a relative humidity of only 15 per cent having been occasionally observed. During the hours of the night the effect of this excessive dryness is partly compensated by a rather abundant formation of dew. In those parts (the eastern Sunda Isles), however, it not unfrequently occurs that lawns are burnt red by the sun's heat, and that even cocoanut palms die for want of water. During the months of December, January, and February the prevailing northwest monsoon brings abundant rainfall. The southern parts of Borneo and Celebes are situated in these regions.

4. A fourth type may be found in the eastern parts of the Archipelago, the Moluccas, where also in January northwestern winds and in August southeastern winds dominate, but where, owing to the fact that the air, whether from west or east, has traveled over a considerable space of water surface heated up to tropical temperature, either monsoon wind gives rise to abundant rainfall. Therefore, two rainy seasons are observed, the principal one about January, and one of secondary importance in July.

In discussing these four types, however, it is distinctly to be understood that the true monsoons are observed only in mid ocean; at land stations and near the coasts, land and sea breezes prevail almost everywhere and are only modified in direction by the monsoon winds. For the same reason a season may be rainy along the coast line and not so at sea a few miles from the coast, because rain is formed only when the air is forced upwards against the sides of the inland mountains, in which case a moderate rainfall at sea, a heavy rainfall at the weather shore, and a dry season at lee side of the isle are observed.

The decrease of the mean temperature of the air with the altitude above the sea level is about 1.1° F. for every 100 meters difference in height.

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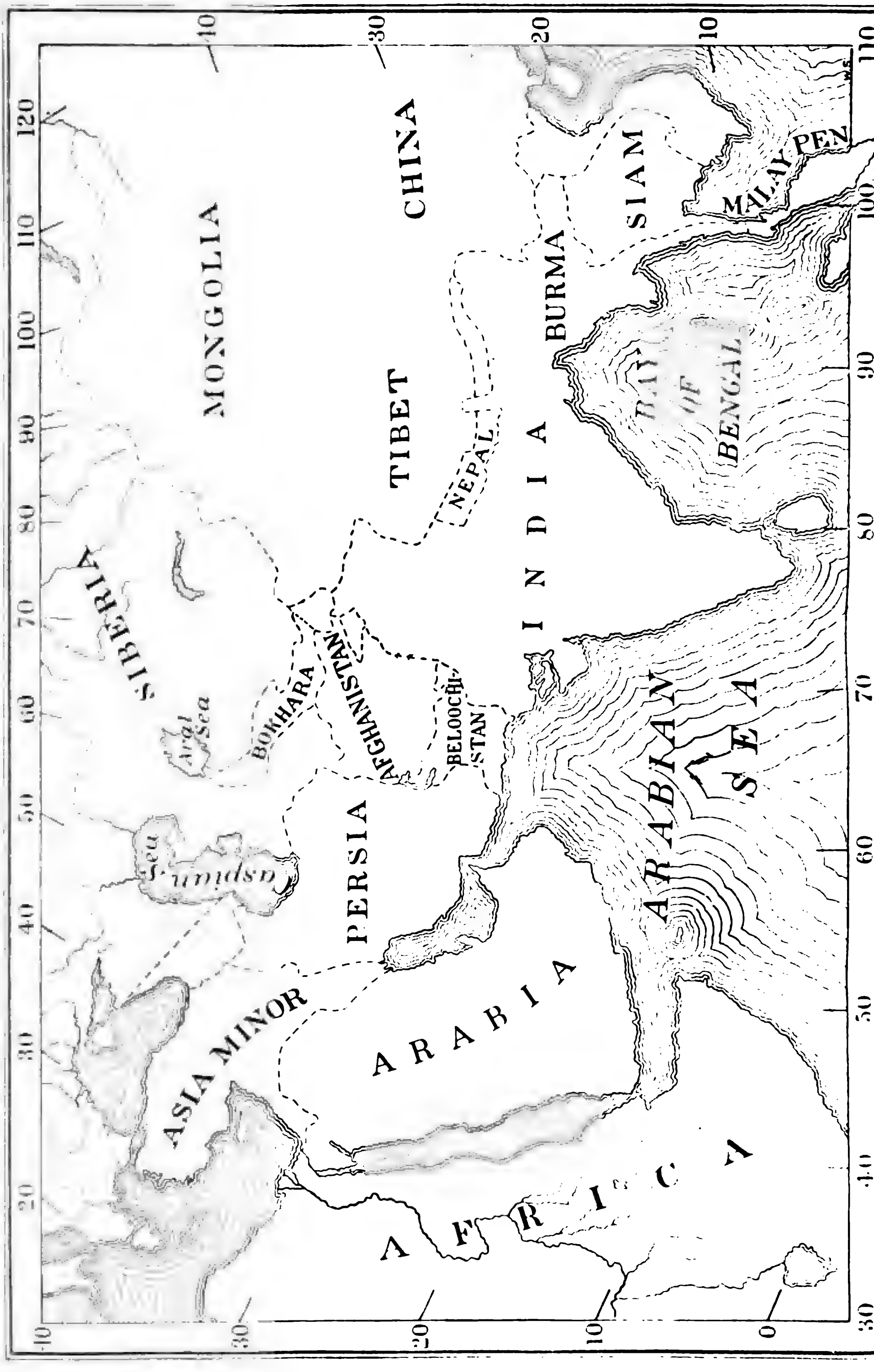
## 12.—CLIMATOLOGY OF SOUTHERN AND WESTERN ASIA.

W. L. DALLAS.

(*With Plate XXXVI.*)

The subject of the present memoir, viz, the climatology of southern and western Asia, divides itself naturally into two parts, the first treating of the countries outside the influence of the massive currents of the Indian Ocean monsoons, the second treating of the countries the climatology of which is more or less controlled by these monsoons. In the former division the weather is determined by ordinary climatological laws depending on the position of the sun in declination, etc., and hence presents the ordinary characteristics of cold, more or less rainy winters, and hot, more or less rainless summers; in the latter division we have, superimposed on these ordinary conditions, modifications




MAP OF SOUTHERN AND WESTERN ASIA

produced by the action of the monsoons so that there occurs an early hot weather, a rainy summer, and a fine winter.

The countries in the first category include Syria and Mesopotamia, Arabia, Persia, Afghanistan, Baluchistan, and Thibet; in the latter category we have Hindostan, Burma, and the Eastern Archipelago. Of course, political and physico-geographical divisions not being necessarily identical, it follows that in some cases the divisions adopted above are not strictly descriptive of the actual limitations of the two classes of weather. Thus the weather in southeastern Arabia is wholly monsoonal, while on the contrary that of northwestern Hindostan partakes of the moonsonal and nonmonsoonal types, but on the whole it will be found that the general weather of the countries in the first category is of the ordinary type, and that of the countries in the second category of the monsoonal type.

Climatology, according to its modern signification, describes the particular condition of the atmosphere (in relation to its heat or cold, its dampness, or dryness) which prevails at any given spot on the earth's surface. The differences in this condition of the atmosphere, which observation has shown to exist in different places are attributable (with a host of minor influences) to three main causes, viz, distance from the equator, altitude, and prevalent air currents. These influences affect climate throughout the world, and it consequently follows that within the countries the climatological features of which we are about to investigate every variety of climate is met with because they, or at least some of them, are close to the equator, and because within their limits there is every variety of altitude and every variety of air currents. It would then be misleading to speak of the climate, say of Persia, as if the conditions of heat and cold, dryness and moisture, were more or less identical throughout the whole of that country, and all that can be attempted is to present the meteorological features of certain selected places, leaving the conditions existing over a very large area of its surface to be estimated from an intelligent consideration of the position of those areas with regard to the three climatological causes noticed above.

In the important question of the temperature of unsettled tracks of country there arises a source of error which can not, however, be allowed for by a consideration of natural causes, and this is the deviation from the correct temperature, which is due to the thermometric exposure adopted by different travelers. Dr. Scully, who, in 1875, made a journey into Yarkand and Kashghar, took with him a portable thermometer shed, which effectually protected the instruments from sky radiation, while it allowed of their free exposure to the air, so that the observations were probably quite comparable with those obtained at ordinary meteorological stations. Similarly, travelers who are able to expose their thermometers in the north verandas of rest or staging bungalows probably register fairly correct readings, but when, as is not infrequently

the case, the only possible place of exposure is the pole of the traveler's tent, the deviation of the thermometric results from the correct temperature must often be very considerable. On this account the thermometric returns of a permanent meteorological station frequently differ largely from the readings recorded (previous to its establishment) by passing travelers, and as observations from established observatories are collected it is not infrequently found that our estimates of the climate of a given place, founded on the occasional observations of travelers or the casual remarks of past residents, have to undergo very large modification.

*Syria and Mesopotamia.*—The most westerly division of the region under review is Syria and Mesopotamia. The division is a large one, and its western and eastern portions differ considerably in climatological characteristics from each other. Unfortunately, it is also a division for which meteorological information is extremely meager. In the western portion of the division no regular meteorological observatory exists, and the information respecting its climatology is derived from the diaries of travelers and explorers.

The maritime plain and the Jordan Valley have a mean annual temperature of 70° F., the extremes being 50° and 85°. The annual rainfall is about 20 inches, the fall taking place during the winter months. These plains are very hot and unhealthy in the summer, more particularly in May, when a dry east wind prevails and is especially trying. The climate of Jerusalem itself is, however, fairly good. A fresh sea breeze blows throughout the day in summer, and the average maximum of that season is only 86° F. August is the hottest month. In winter there are occasional falls of snow, and the temperature sinks several degrees below 32° F.

To the eastward of the Jordan the climate is one of extremes; the thermometer may frequently fall during the night below freezing point and rise next day to 80°. In the winter the mountains remain snow covered. In the southeastern portion of the division a meteorological station has been established at the important city of Bagdad, and the following table shows the meteorological records received:

| Month. | Average maximum. | Average minimum. | Mean. |
|---|---|---|---|
| | °F. | °F. | °F. |
| January | 68 | 45 | 56 |
| February | 67 | 41 | 54 |
| March | 75 | 47 | 61 |
| April | 84 | 54 | 69 |
| May | 88 | 61 | 75 |
| June | 99 | 71 | 85 |
| July | 110 | 78 | 94 |
| August | 109 | 81 | 95 |
| September | 106 | 72 | 89 |
| October | 92 | 58 | 75 |
| November | 79 | 49 | 64 |
| December | 74 | 44 | 59 |

The mean temperature is lowest in February (54.1° F.) and highest in August (94.9° F.), the mean annual temperature being 73°. The

maxima are high from April to October, the highest recorded being 113.3° F. The daily range of temperature is large throughout the year, varying from 22° in January to 34° in October. The wind is generally northerly to easterly in all months of the year. The air is dry, especially in the summer. Rain fell on only 5 days (2 days in January, 2 days in February, and 1 day in November), and the total amount of rainfall for the year was only 1.35 inches.

In lower Mesopotamia frost is exceptional, while in summer the heat is very intense, and during the whole hot season there is no rain. The only thing which alleviates the great heat is the heavy night dew. During the sand storms that come up from the west Arabian desert the thermometer sometimes rises to 122° F., and this heat prevails throughout the greater part of the valley of the Euphrates and Tigris. In winter, in upper Mesopotamia, the cold is severe. From the coasts of the Mediterranean eastward the cold increases. Snow and ice are not infrequent in the upper Mesopotamian plain, and when the cold north wind prevails temperature falls as low as 14°.

It will thus be seen that over the greater part of the division under review the climate is generally one of strong contrasts. The only exception is the maritime plain on the Mediterranean, where the climate, though hot, is equable and moist and the rainfall fairly heavy. On proceeding eastward, the contrasts of climate strengthen, the summers become intensely hot, the winters very cold, and the rainfall, as is seen in the case of Bagdad, becomes nil in summer and only very slight in winter. The Bagdad registers show that the wind directions are largely northerly. In winter this direction is due to the outflow from the high-pressure area which extends across central Europe, and is a prolongation of the central Asian anticyclone; in summer it is due to the presence of a low-pressure area over the Indus Valley, Baluchistan, and the Persian Gulf. In both cases there is nothing to give moisture to the winds, and hence the generally dry weather which prevails over the greater part of the division. In the maritime belt adjoining the Mediterranean the prevailing direction is northwesterly and sea breezes prevail during the day, hence the moisture is greater and the rainfall heavier. The snow which falls on the hills is due, as is the case in countries farther to the eastward, to moisture derived from the upper currents.

*Arabia.*—The second division includes the whole of Arabia. For this division, also, meteorological information is exceedingly meager. One settled observatory exists at Aden, but for all the remainder of the country the only information obtainable is that which is derived from the diaries of occasional travelers and the casual remarks of residents. As these remarks are generally called forth on the occasion of exceptional phenomena—for example, excessive heat—it is probable that there is always a tendency to give the climate stronger contrasts than is fairly its due.

Aden is situated in the southwest corner of the division, and observations for eleven years are available. The mean annual temperature is 82.5° F., the warmest month being June, with a mean of 89.5°, and the coolest January, with a mean of 75.2°. The mean daily range is only 10.8°, the range being smallest, 7.4°, in January, and greatest, 14.3°, in April. The mean maximum temperature for the whole year is 88°, the lowest being 78.9°, in January, and the highest 95°, in June. The absolute maximum is 101.1°, recorded in May. The mean minimum temperature for the whole year is 77°, the lowest being 71.5°, in January, and the highest 84°, in June, while the absolute minimum is 65.3°, in January. Easterly winds are very prevalent, after which calms are the most numerous, but from June to August, when the southwest monsoon is strongest, a considerable proportion of southwesterly and southerly winds prevail. The mean humidity of the whole year is 74 per cent, the highest mean being 80 per cent, in July, the lowest 64 per cent, in October. The sky is about half covered in January, February, and November, and is nearly clear in the other months. No rain has been recorded in June or October, but showers have occurred in all the other months.

If we accept this station as representing the southwest of Arabia, it is evident that the climate, though hot and trying, is fairly equable and presents none of the large contrasts met with in the first division. The annual range of temperature is comparatively small, the air is moist throughout, the rainfall is light and very uncertain, and the winds are fairly steady.

Arabia, taking it as a whole, is an overheated and far from fertile country, but in some respects the climate has been maligned, and to the southeast of Mecca there is a region celebrated for the salubrity of its climate.

In the Sinaitic Peninsula the climate resembles that of Syria, being rainy in the winter, the early spring, and late autumn, but clear and dry at other times. The summer heat is excessive (115° to 120° F.), while the winter cold is considerable. Along the Red Sea littoral the climate is very hot, unhealthy, and feverish. It is very dry from August to November. Rain commences in December, but is very irregular. The District of Yemen includes the southwest corner of the Peninsula of Arabia and its climate, or at least its coast climate, is represented by Aden, the returns from which station have been discussed above. Along the coast of the Indian Ocean is the Province of Hadramaut, a sterile expanse of mountain and hill. No part of Arabia is less explored than this, and all that is known is that the climate is intensely hot and damp. The southwest monsoon gives heavy falls of rain during the summer, and the hills are cut up by the resulting torrents, but the soil is everywhere sterile. The Province of Oman occupies the southeast corner of Arabia. The climate here, though still intensely hot, is less trying than in some other parts of the Peninsula, extensive tracts of vegetation serving to ameliorate the

great heat. On the coast, however, the land is rocky and the climate is undoubtedly extremely trying.

The principal town of the province is Muscat, and the summer climate of that place is an exceptional horror. Abdur Razak (May, 1442) left on record that "the heat is so intense that it burned the marrow in the bones; the sword in its scabbard melted like wax, and the gems which adorned the handle were reduced to coal. In the plains the chase became a matter of perfect ease, for the desert was filled with roasted gazelles."

The rainfall is only 3½ inches, and all falls within two or three weeks. A black bulb solar thermometer has registered 187° F. in the sun.

The central parts of Arabia are occupied by the Province of Nejo (3,000 feet above mean sea level). Here the climate, though hot during the day, is cool at night and the prevailing east and northeast winds are cool and refreshing. The spring and autumn rains seldom fail, and the province forms a veritable oasis girdled by the burning desert.

To dismiss the climatology of Arabia without any mention of the celebrated simoon, would perhaps to many minds be to leave the subject incomplete. There is, however, very little known as to this interesting phenomenon. Neither season nor locality nor frequency of occurrence has been catalogued, and all that can be concluded is that the simoon is a small cyclonic storm traveling across the desert and not infrequently passing from the desert into more fertile regions. The spiral circulation of the winds characteristic of cyclonic storms appears to carry toward the central area the heavy, unhealthy malarious gases with which the atmosphere of the desert abounds, so that when the calm center crosses the overtaken traveler he has to breathe a concentrated atmosphere of mephitic vapors collected from the desert districts over which the cyclone has passed.

*Persia.*—We now turn northward to the country of Persia. For this division we have meteorological observations from the stations of Bushire, Borasjoor, Shiraz, Dehbid, Abadeh, Kashan, Kum, and Mesched, running from the south to the north. The following table gives the principal meteorological features of these stations:

| Place. | Data. (Temperature, ° F.) | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bushire | Average maximum | 64 | 68 | 79 | 82 | 88 | 95 | 95 | 98 | 95 | 89 | 79 | 66 |
| | Average minimum | 52 | 55 | 64 | 68 | 77 | 82 | 85 | 85 | 80 | 72 | 64 | 53 |
| | Mean | 58 | 61 | 71 | 75 | 83 | 88 | 90 | 92 | 88 | 81 | 71 | 59 |
| | Humidity (per cent) | 81 | 77 | 64 | 56 | 56 | 62 | 63 | 72 | 63 | 59 | 69 | 68 |
| Borasjoor | Average maximum | 62 | 66 | 79 | 87 | 99 | 105 | 107 | 107 | 101 | 94 | 79 | 62 |
| | Average minimum | 52 | 52 | 63 | 66 | 75 | 85 | 89 | 88 | 81 | 76 | 64 | 52 |
| | Mean | 57 | 59 | 71 | 77 | 87 | 95 | 98 | 98 | 91 | 85 | 72 | 57 |
| | Humidity (per cent) | (?) | (?) | (?) | 34 | 35 | 44 | 19 | 20 | 11 | 21 | 19 | 35 |
| Shiras | Average maximum | 64 | 62 | 82 | 85 | 93 | 101 | 105 | 104 | 98 | 92 | 83 | 74 |
| | Average minimum | 26 | 23 | 39 | 43 | 54 | 62 | 66 | 65 | 57 | 48 | 40 | 32 |
| | Mean | 42 | 48 | 57 | 68 | 77 | 86 | 90 | 86 | 78 | 65 | 55 | 46 |
| | Humidity (per cent) | 66 | 85 | 75 | 65 | 54 | 49 | 46 | 43 | 48 | 43 | 64 | 77 |

| Place. | Data. (Temperature, ° F.) | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dehbid | Average maximum | 35 | 42 | 53 | 59 | 69 | 80 | 87 | 83 | 70 | 62 | 46 | [illegible] |
| | Average minimum | 20 | 23 | 30 | 35 | 40 | 40 | 47 | 47 | 40 | 33 | 24 | [illegible] |
| | Mean | 31 | 37 | 49 | 56 | 65 | 73 | 75 | 73 | 62 | 52 | 40 | [illegible] |
| | Humidity (per cent) | 1 | (?) | 6 | 43 | 7 | 7 | 18 | 23 | (?) | (?) | (?) | [illegible] |
| Abadeh | Average maximum | 64 | 62 | 69 | 73 | 81 | 89 | 94 | 93 | 90 | 80 | 74 | 74 |
| | Average minimum | 22 | 23 | 32 | 38 | 45 | 52 | 56 | 54 | 47 | 39 | 32 | 21 |
| | Mean | 40 | 42 | 55 | 59 | 66 | 73 | 77 | 75 | 69 | 61 | 53 | [illegible] |
| | Humidity (per cent) | 74 | 80 | 50 | 48 | 51 | 49 | 46 | 44 | 49 | 71 | 77 | [illegible] |
| Kashan | Average maximum | 41 | 47 | 60 | 71 | 80 | 89 | 93 | 90 | 83 | 69 | 54 | [illegible] |
| | Average minimum | 20 | 33 | 45 | 49 | 59 | 69 | 73 | 70 | 61 | 51 | 45 | [illegible] |
| | Mean | 35 | 40 | 53 | 60 | 69 | 79 | 83 | 80 | 72 | 60 | 49 | [illegible] |
| Kum | Average maximum | 44 | 51 | 66 | 74 | 82 | 93 | 96 | 92 | 85 | 71 | 58 | [illegible] |
| | Average minimum | 36 | 38 | 49 | 53 | 61 | 69 | 73 | 71 | 62 | 54 | 46 | [illegible] |
| | Mean | 40 | 45 | 58 | 63 | 72 | 81 | 85 | 81 | 74 | 62 | 52 | 44 |
| Mesched | Average maximum | 46 | 50 | 58 | 72 | 82 | .... | .... | 82 | 73 | 64 | .... | 46 |
| | Average minimum | 30 | 31 | 40 | 51 | 58 | .... | .... | 61 | 56 | 46 | .... | 30 |
| | Mean | 38 | 41 | 49 | 61 | 70 | .... | .... | 72 | 63 | 55 | .... | 38 |

Every variety of climate is to be found in Persia. In the Caspian provinces the climate is of the southern temperate zone, with an amount of humidity rarely met with out of the Tropics. Rain is frequent, one day in five having rain, and the weather "moist, muggy, and villainous" in the summer, and damp and muddy in the winter, with a bitter wind from snow-clad mountains.

The central regions, exemplified by the stations of Kum, Kashan, and Abadeh, have a fairly temperate climate, but sharp frost prevails in the winter (Abadeh, absolute minimum 13°), and in the summer the shade temperature exceeds 90° (Kum, absolute maximum 102°; Abadeh, 101°). Shiraz, which is well in the south, has been greatly praised by Persian poets for the salubrity of its climate, but the mean day temperature in June, July, and August varies between 100° and 105° (absolute maximum 107°), while, on the contrary, in January and February the frost at night is very sharp (absolute minimum 18°). The stations Borasjoor and Bushire show the conditions which prevail on the borders of the Persian Gulf. At Bushire itself the temperature is ameliorated by a sea breeze, and the highest mean monthly temperature is 98° in August (absolute maximum 111.5°), but at Borasjoor, a few miles inland, the mean is as high as 107° in July and August, and the absolute maximum is 114°. Daliki, a village a few miles from Borasjoor, the Rev. H. Martyn describes as "one of nature's ulcers," a rhetorical flight attributable to the fact that at the time of writing the thermometer was standing at 126° in the tent. For Mesched, in the northeast of Persia, the returns are incomplete, but apparently the weather there is somewhat less cold in winter and less hot in summer than in some other parts of Persia. The pleasantest part of the country is the center, where, though some parts of the summers are a trifle too hot and some parts of the winters are too cold, the intervening periods are characterized by exquisite weather.

At Bushire moderate rain falls in December, January, and February (3½ inches each month), and light rain in March, April, and November. The remaining months are fine. At Borasjoor rain falls in January, February, November, and December, the remaining months being fine,

with strong, hot winds. At Shiraz the weather is rainy in the winter months, and occasional thunderstorms occur in the summer. Dehbid is a hill station 7,500 feet above mean sea level, and is the coldest inhabited place in Persia. The weather is fine from June to October, but snow falls in January, February, November, and December, and rain showers in the other months. At Abadeh and Kashan the weather is cloudy, with occasional snow and rain in the winter, windy in the spring, and very fine in the summer. At Kum there is no snow, but the weather is showery and unsettled, except in June, July, August, and September.

The following general notices of the climates of the different provinces of Persia are derived from various sources:

The northwest of Persia is occupied by the Province of Azerbaïjan. It is a mountainous country and its climate is one of extremes. The summer climate is the climate of India; the winter climate is the climate of Canada.

The southeastern provinces form part of Baluchistan, and the meteorological records of Bushire apply in part to this region. On the coast the heat is intense, and in the summer time the exhausted gazelles are said to lie down and suffer themselves to be captured by the hunter. Inland there is a mountain plateau, and on some of the higher peaks eternal snow. At Lingah it only rains during a period of two or three weeks in the year. Of Bunder Abbas, on the same coast, Fitch, an Elizabethan merchant (1583), writes, "The air seems to be on fire," and Herbert says, "The air is insufferable, so as some used to lie naked in troughs filled with water, which, nevertheless, parboils their flesh," while the British tars declared "there was but an inch deal betwixt Gomberoon (Bunder Abbas) and hell."

The Persian Gulf climate is fairly agreeable in the winter months, but in the summer the climate is most trying. Under awnings on the deck of a gulf steamer the thermometer rises to 120° F., while the intense heat is aggravated by the high humidity.

*Baluchistan.*—To the eastward of southern Persia is the Province of Baluchistan. The climate of this province is similar to that of Persia. The coast is somewhat more exposed to the influence of the southwest monsoon than the Persian coast, which is protected by Arabia, but is still intensely hot. In the highlands in the north every variety of climate is obtainable, but the contrasts are large, as will be seen by the following table, which gives the climatology of Quetta, 5,000 feet above mean sea level:

| Place. | Data. (Temperature, ° F.) | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quetta | Average maximum | 54 | 57 | 71 | 81 | 86 | 88 | 94 | 90 | 84 | 75 | 64 | 51 |
| | Average minimum | 32 | 33 | 41 | 47 | 52 | 56 | 65 | 62 | 44 | 39 | 31 | 31 |
| | Mean | 43 | 45 | 55 | 64 | 68 | 72 | 79 | 76 | 64 | 57 | 47 | 41 |
| | Humidity (per cent) | 65 | 61 | 47 | 42 | 85 | 42 | 54 | 61 | 41 | 42 | 48 | 76 |

The highest temperature observed is 99°, in July; the lowest 22°, in January; so that the extremes of climate are large. Much snow falls during January and February, and heavy rain showers occur in March and April, but from May up to the close of the year only occasional showers occur and the Indian monsoon is not felt.

*Afghanistan.*—The climatology of Afghanistan is similar to that of northern and central Persia. It is one of strong contrasts and of large extremes. The information as to its climate is mainly derived from the records of the Afghan Boundary Commission, and refers to the period from October, 1884, to October, 1886. The following are the meteorological records:

| Place. | Data. (Temperature, ° F.) | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Afghanistan.... | Average maximum | 42 | 43 | 61 | 69 | 85 | 99 | 98 | 100 | 85 | 76 | 65 | 51 |
| | Average minimum | 28 | 23 | 36 | 44 | 53 | 64 | 62 | 65 | 51 | 40 | 35 | 28 |
| | Mean | 34 | 32 | 45 | 56 | 67 | 75 | 80 | 81 | 72 | 59 | 50 | 40 |

Northerly (northwest to northeast) winds prevail, as in Persia, all the year round. Hot winds loaded with dust prevail during the day in summer, and the thermometer in open tents in June, July, and August sometimes rises to 110°.

In the winter the cold is often intense, and on one occasion the thermometer fell to —12° F. On several occasions the thermometer never rose above 20° F. during the day. Heavy snowstorms occur from January to March, and heavy rain showers during April, but from May to October the weather is fine. In November the weather gets changeable and unsettled and light snow falls with raw, chilly, disagreeable weather.

*The Pamirs.*—To the north and northeast of Afghanistan lies the little-known region of the Pamirs. This region is occupied by high mountains, elevated table-lands, and deep valleys, and the variations of climate are very large. Most of the meteorological observations obtainable, however, refer to the stations of Chitral and Gilgit, both occupying comparatively low elevations; consequently, there are no very striking features in the temperature records given below. On the higher elevations the cold from October to May is intense.

| Place. | Data. (Temperature, ° F.) | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pamirs ........ | Average maximum | 50 | 50 | 65 | 66 | [1]61 | 78 | 87 | 94 | 80 | 70 | 58 | 50 |
| | Average minimum | 34 | 33 | 47 | 46 | 26 | 48 | 64 | 64 | 52 | 45 | 33 | 32 |
| | Mean | 42 | 42 | 56 | 56 | 44 | 63 | 76 | 79 | 66 | 58 | 46 | 41 |

[1] Recorded at high elevations.

During January the weather is cloudy and dull, with snow off and on throughout the month, with a cold southwest wind. In February there is a considerable proportion of easterly winds. The weather, however, remains cloudy, and when the wind changes to southwest or southeast snow falls. In March the weather is showery, snow and sleet falling every few days. During April the mornings are ordinarily very bright, but after noon clouds collect and thunderstorms occur almost every evening. May has occasional snowstorms, and very strong, cold winds prevail on the higher passes and hills. In June and July the weather is fine and hot, but extraordinarily strong westerly winds prevail during the day, the wind falling almost calm at night. August is also a fine month, and has generally less wind than the two preceding months. Thunderstorms in the afternoon recommence toward the close of the month, when some showers also fall. During September the weather is fine and bright, with occasional showers and light westerly winds. Frost commences even in the valleys toward the close of the month; October, November, and December are more or less dull, cloudy, cheerless months. Drizzling rain and snow commence in October or November, according as the season is late or early, and intense frost is reported on the higher hills and passes in November or early in December, and lasts throughout the winter.

*Thibet.*—For the following information regarding south Thibet I am indebted to my friend Captain Bower. Captain Bower crossed the frontier into Thibet on the 3d of July, 1891, at Lanak, and from that date until the 14th of November he traveled eastward at an average elevation of 15,000 or 16,000 feet. During July the temperature at daybreak varied between 18° and 28° F.; during August, between 19° and 30° F.; during September, between 19° and 29° F.; during October, between 21° F. and —15° F., and during November, between 2° F. and —15° F. Snow fell even in July and August; and from September onward the falls were of almost daily occurrence; winds, clouds, and storms all came from west and southwest; and it is remarkable that when, as occasionally happened, the wind shifted to east the clouds vanished. Heavy rain fell very frequently, and Captain Bower says that the water courses, etc., with which the hillsides were cut up are evidences that this is the normal condition. These southwesterly winds and heavy rainfalls in a region outside the influence of the monsoon are very interesting. In a paper communicated by the author to the American Meteorological Journal it was pointed out that in the summer and in this part of the world the region of doldrums and of principal ascensional movement lies over the Gangetic plain, and it is evident that the southwesterly winds in these Thibetan highlands form the return current from this doldrum region towards the northern temperate zone and that the rainfall is derived from this upper current. In India, in the winter months, there is ample evidence that much moisture is contained in these upper return currents.

*Monsoon climatology.*—We now turn to a very brief résumé of the climatology of those countries which lie under the influence of the monsoons.

At the height of the summer season, when the sun hangs over the northern tropic, the band of lowest pressure over the Indian region lies over Burma, the Gangetic plain, Baluchistan, and the Persian Gulf, while the highest pressures are found over the Australasian region and the South Indian Ocean; at the height of the winter season the band of lowest pressure lies in about 12° south latitude, and the highest pressures are over the Asiatic Continent. This change in the distribution of pressure is accompanied by a reversal in the surface currents of air, the summer being accompanied by a flow of surface air from the Southern to the Northern Hemisphere, the winter by a flow of surface air from the Northern to the Southern Hemisphere. It would be out of place here to describe how the current from the high-pressure area in the south seas is pushed forward by a *vis à tergo*, or how its advance is smoothed by solar action over southern Asia, it being sufficient from a climatological point of view to note the weather changes which result from this reversal of the air currents.

The summer monsoon is then roughly a current from the southward. In its passage from southern latitudes it passes over an unbroken oceanic expanse and reaches southern Asia as a vapor-laden current. It reaches Hindostan and neighboring countries at a time when the sun is practically vertical; and though it materially reduces the previously existing heat, its action in this respect is comparatively slight. Hence, during the summer monsoon the climate of the countries affected by it is characterized by great dampness, much cloud, heavy rain, and great heat. Roughly speaking, the arrival and departure of the monsoon, and its intensity (by which is meant its force and its rain-bearing qualities) is inversely as the latitude of the place of observation. Thus at Cochin (latitude 9° 58′) the monsoon commences at the end of May, and the rainfall is 115 inches in the year; at Bombay (latitude 18° 54′) it commences in the first week of June, and the annual rainfall is 74 inches; at Calcutta (latitude 22° 32′) it commences about the 10th of June, and the annual rainfall is 65 inches; at Allahabad (latitude 25° 26′) it commences about the 15th of June, and the annual rainfall is 38 inches; and, finally, at Lahore (latitude 31° 34′) it commences about the end of June, and the annual rainfall is 22 inches. The following table gives the climatological figures of these five stations and will serve to elucidate the main features of the weather over India:

| Place. | Data. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cochin | Temperature (° F.): | | | | | | | | | | | | |
| | Average maximum | 89 | 90 | 91 | 91 | 89 | 85 | 83 | 83 | 84 | 86 | 87 | 88 |
| | Average minimum | 71 | 73 | 76 | 78 | 77 | 74 | 74 | 74 | 74 | 74 | 74 | 72 |
| | Mean | 79 | 80 | 83 | 84 | 82 | 78 | 77 | 79 | 78 | 79 | 79 | 79 |
| | Humidity (per cent) | 70 | 72 | 75 | 77 | 81 | 88 | 88 | 87 | 86 | 84 | 81 | 75 |
| | Rain (inches) | 0.9 | 0.7 | 2.1 | 4.4 | 12.7 | 30.7 | 22.7 | 12.4 | 9.4 | 12.1 | 5.1 | 1.9 |
| | Days of rainfall | 1 | 2 | 5 | 8 | 17 | 27 | 27 | 22 | 19 | 19 | 12 | 5 |
| Bombay | Temperature (° F.): | | | | | | | | | | | | |
| | Average maximum | 82 | 82 | 85 | 88 | 90 | 88 | 85 | 84 | 84 | 87 | 86 | 84 |
| | Average minimum | 68 | 69 | 74 | 77 | 80 | 80 | 77 | 77 | 76 | 76 | 73 | 70 |
| | Mean | 74 | 75 | 79 | 82 | 85 | 83 | 81 | 80 | 80 | 81 | 80 | 76 |
| | Humidity (per cent) | 70 | 69 | 73 | 75 | 75 | 82 | 87 | 87 | 86 | 81 | 71 | 70 |
| | Rain (inches) | 0.1 | .... | .... | .... | 0.5 | 20.8 | 24.7 | 15.1 | 10.8 | 1.8 | 0.5 | 0.1 |
| | Days of rainfall | 1 | 1 | .... | .... | 2 | 20 | 29 | 26 | 21 | 7 | 1 | .... |
| Calcutta | Temperature (° F.): | | | | | | | | | | | | |
| | Average maximum | 77 | 82 | 91 | 96 | 94 | 91 | 88 | 87 | 87 | 87 | 82 | 76 |
| | Average minimum | 55 | 61 | 70 | 76 | 77 | 79 | 78 | 78 | 78 | 75 | 64 | 56 |
| | Mean | 65 | 70 | 79 | 85 | 85 | 84 | 83 | 82 | 82 | 80 | 72 | 65 |
| | Humidity (per cent) | 71 | 69 | 69 | 71 | 76 | 84 | 87 | 89 | 88 | 83 | 74 | 72 |
| | Rain (inches) | 0.4 | 1.0 | 1.3 | 2.3 | 5.6 | 11.8 | 13.0 | 13.9 | 10.0 | 5.4 | 0.6 | 0.3 |
| | Days of rainfall | 2 | 3 | 3 | 5 | 10 | 18 | 24 | 24 | 18 | 8 | 2 | 1 |
| Allahabad | Temperature (° F.): | | | | | | | | | | | | |
| | Average maximum | 74 | 80 | 93 | 104 | 106 | 104 | 93 | 91 | 92 | 89 | 82 | 74 |
| | Average minimum | 48 | 51 | 62 | 72 | 78 | 83 | 80 | 79 | 77 | 67 | 54 | 47 |
| | Mean | 61 | 66 | 78 | 88 | 92 | 91 | 85 | 84 | 83 | 78 | 68 | 61 |
| | Humidity (per cent) | 68 | 58 | 43 | 33 | 40 | 55 | 81 | 82 | 80 | 69 | 64 | 69 |
| | Rain (inches) | 0.8 | 0.4 | 0.4 | 0.2 | 0.3 | 4.6 | 11.9 | 9.6 | 6.7 | 2.3 | 0.2 | 0.2 |
| | Days of rainfall | 2 | 2 | 1 | 1 | 2 | 7 | 17 | 18 | 11 | 3 | .... | 1 |
| Lahore | Temperature (° F.): | | | | | | | | | | | | |
| | Average maximum | 68 | 71 | 83 | 95 | 102 | 107 | 99 | 98 | 97 | 93 | 81 | 71 |
| | Average minimum | 43 | 46 | 57 | 66 | 73 | 81 | 81 | 80 | 75 | 62 | 49 | 43 |
| | Mean | 54 | 59 | 69 | 81 | 88 | 93 | 89 | 88 | 85 | 77 | 64 | 55 |
| | Humidity (per cent) | 60 | 57 | 48 | 37 | 33 | 37 | 58 | 61 | 55 | 46 | 47 | 56 |
| | Rain (inches) | 0.7 | 1.1 | 1.1 | 0.6 | 0.9 | 1.8 | 7.4 | 4.6 | 2.4 | 0.6 | 0.2 | 0.5 |
| | Days of rainfall | 2 | 3 | 2 | 3 | 3 | 3 | 7 | 6 | 4 | 1 | 1 | 2 |

The above figures show as regards temperature that the hottest month at Cochin is April; at Bombay it is May; at Calcutta it is April; at Allahabad, May; and, finally, at Lahore, June. At the first four stations the weather is purely monsoonal, nearly all the rainfall occurring during the prevalence of the summer monsoon; but at Lahore the weather partakes of the characteristics of monsoonal and extramonsoonal countries, for while the heaviest rainfall is in July, yet in the winter and spring there are showers such as prevail in Afghanistan, Persia, etc.

*The winter monsoon.*—The cold-weather monsoon is the reverse of the summer monsoon. It consists of a surface flow of air from the Northern to the Southern Hemisphere. It is of land origin, and is hence a dry, cold current over the greater part of its course, but when that course leads it across the open sea it absorbs moisture and loses its dry characteristic, and though seldom giving rain to any part of the Indian region, it is the principal rain-bearing current in the Eastern Archipelago.

*Burma.*—The Province of Burma has monsoon conditions as strongly marked as any part of India and the contrasts of climate are very large. Thus, on the coast the annual rainfall is nearly 200 inches (Akyab, 196 inches, and Moulmein, 189 inches), while at Mandalay, in upper Burma, it is only 27 inches, and at some other places in the Irrawaddy Valley

is even less. On the coast from April to October rain falls almost daily, the temperature is very steady, and the mean daily range only about 10°, while from November to March, on the contrary, the weather is fine, temperature subject to moderate changes, and the mean daily range about 20° to 25°. In upper Burma, on the other hand, though most of the rain falls, as on the coast, between May and October, the amount is small and only one day in four or five has any rainfall, while from December to April there is practically no rain. The temperature changes are large, and the mean daily range is as much as 30° in February and about 15° in June, July, and August.

*The Malay Peninsula.*—The climate of the Malay Peninsula is everywhere and throughout the whole year moist and hot. The mean annual temperature is about 80° F., and the temperature is very equable throughout the year. Both the northeast and southwest monsoons bring rain, which is distributed more or less evenly throughout the year. There are about 190 rainy days in the year, and the mean rainfall is from 90 to 130 inches.

## CLIMATOLOGICAL TABLES FOR SOUTHERN ASIA.

### BAGDAD.

| Months. | Temperature. Mean maxima. | Mean minima. | Mean temperature. | Mean daily range. | Absolute maximum. | Absolute minimum. | Prevailing wind direction. | Number of days' rainfall. | Amount of rain and snow. | Mean humidity. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ° F. | ° F. | ° F. | ° F. | ° F. | ° F. | | | In. | P. ct. |
| January | 67.6 | 45.2 | 56.4 | 22.4 | 71.0 | 39.0 | N.-NE. | 2 | 0.70 | 66 |
| February | 66.7 | 41.4 | 54.1 | 25.3 | 70.5 | 37.0 | N.-NE. | 2 | 0.45 | 31 |
| March | 74.6 | 47.3 | 61.0 | 27.3 | 79.8 | 44.0 | N.-NE. | 0 | 0.00 | 42 |
| April | 84.1 | 53.8 | 69.0 | 30.3 | 87.4 | 50.0 | N. | 0 | 0.00 | 56 |
| May | 88.2 | 61.2 | 74.7 | 27.0 | 91.8 | 55.0 | N. | 0 | 0.00 | 52 |
| June | 98.8 | 71.3 | 85.1 | 27.5 | 107.3 | 60.9 | N. | 0 | 0.00 | 27 |
| July | 109.5 | 78.0 | 93.8 | 31.5 | 112.8 | 73.7 | N. | 0 | 0.00 | 35 |
| August | 108.7 | 81.0 | 94.9 | 27.7 | 113.3 | 73.7 | N.-NE. | 0 | 0.00 | 39 |
| September | 105.9 | 72.3 | 89.1 | 33.6 | 111.8 | 64.9 | N.-NE. | 0 | 0.00 | 44 |
| October | 91.9 | 58.0 | 75.0 | 33.9 | 102.8 | 52.0 | NE. | 0 | 0.00 | 42 |
| November | 78.9 | 49.2 | 64.1 | 29.7 | 84.4 | 48.0 | N. | 1 | 0.20 | 32 |
| December | 73.7 | 44.1 | 58.9 | 29.6 | 78.9 | 36.5 | N.-NE. | 0 | 0.00 | 47 |

### ADEN.

| Months. | Mean maxima. | Mean minima. | Mean temperature. | Mean daily range. | Absolute maximum. | Absolute minimum. | Prevailing wind direction. | Number of days' rainfall. | Amount of rain and snow. | Mean humidity. |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 78.9 | 71.5 | 75.2 | 7.4 | 82.8 | 65.8 | E.-NE. | 0 | 0.00 | 72 |
| February | 81.8 | 73.2 | 77.5 | 8.6 | 85 1 | 69.1 | E.-NE. | 1 | 0.16 | 78 |
| March | 85.2 | 73.0 | 79.1 | 12.2 | 94.7 | 69.3 | E.-NE. | 0 | 0.00 | 73 |
| April | 91.8 | 77.5 | 84.6 | 14.3 | 100.9 | 73.4 | E. | 0 | 0.00 | 73 |
| May | 94.4 | 81.6 | 88.0 | 12.8 | 101.1 | 76.1 | E. | 0 | 0.00 | 75 |
| June | 95.0 | 84.0 | 89.5 | 11.0 | 98.9 | 80.4 | Calm. | 0 | 0.00 | 77 |
| July | 91.9 | 80.3 | 81.1 | 11.6 | 99.7 | 74.7 | S.-SW. | 0 | 0.00 | 80 |
| August | 89.6 | 77.7 | 83.7 | 11.9 | 98.8 | 72.7 | S.-SW. | 0 | 0.00 | 79 |
| September | 91.4 | 80.0 | 85.7 | 11.4 | 96.1 | 73.4 | Calm-E. | 0 | 0.00 | 74 |
| October | 90.6 | 77.3 | 84.0 | 10.1 | 99.1 | 73.9 | E. | 0 | 0.00 | 64 |
| November | 84.7 | 75.1 | 79.9 | 9.6 | 91.5 | 72.7 | E. | 1 | 0.14 | 72 |
| December | 81.0 | 72.8 | 76.9 | 8.2 | 85.0 | 67.8 | E. | 0 | 0.00 | 71 |

*Climatological tables for southern Asia*—Continued.

BUSHIRE.

| Months. | Temperature. Mean maxima. | Mean minima. | Mean temperature. | Mean daily range. | Absolute maximum. | Absolute minimum. | Prevailing wind direction. | Number of days' rainfall. | Amount of rain and snow. | Mean humidity. |
|---|---|---|---|---|---|---|---|---|---|---|
| | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | | | *In.* | *P. ct.* |
| January | 64.1 | 52.0 | 58.4 | 12.1 | 73.6 | 44.8 | SE. | 4 | 1.82 | 81 |
| February | 67.8 | 54.5 | 61.1 | 13.3 | 80.6 | 47.3 | NE.-E. | 3 | 1.09 | 77 |
| March | 78.8 | 64.1 | 71.3 | 14.7 | 96.5 | 50.3 | NE.-NW. | 0 | 0.00 | 64 |
| April | 82.0 | 68.2 | 75.1 | 13.8 | 93.5 | 57.2 | NE.-NW. | 1 | 0.02 | 56 |
| May | 88.2 | 76.7 | 82.5 | 11.5 | 98.5 | 66.1 | NW. | 1 | 0.13 | 56 |
| June | 94.7 | 82.2 | 88.4 | 12.5 | 107.5 | 75.9 | Variable. | 0 | 0.00 | 62 |
| July | 95.4 | 85.3 | 90.3 | 10.1 | 100.5 | 78.7 | NW. | 0 | 0.00 | 63 |
| August | 98.0 | 84.9 | 91.5 | 13.1 | 111.5 | 79.9 | E. | 0 | 0.00 | 72 |
| September | 95.2 | 79.6 | 87.5 | 15.6 | 104.0 | 75.0 | SE. | 0 | 0.00 | 63 |
| October | 88.9 | 72.4 | 80.7 | 16.5 | 101.0 | 64.2 | NE. | 0 | 0.00 | 59 |
| November | 79.0 | 63.6 | 71.3 | 15.4 | 86.6 | 55.7 | NE. | 5 | 3.40 | 69 |
| December | 66.1 | 32.6 | 59.4 | 13.5 | 75.6 | 43.8 | NE. | 4 | 1.97 | 68 |

BORASJOOR.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 62 | 22 | 57 | 10.0 | 67 | 49 | NW. | 4 | ...... | (?) |
| February | 66 | 52 | 59 | 14.0 | 75 | 50 | SW.-NW. | 4 | ...... | (?) |
| March | 79 | 63 | 71 | 15.9 | 90 | 52 | Calm. | 1 | ...... | 19 |
| April | 87 | 66 | 77 | 21.0 | 95 | 66 | SW.-NW. | 0 | ...... | 34 |
| May | 99 | 75 | 87 | 24.0 | 113 | 66 | NW. | 1 | ...... | 35 |
| June | 105 | 85 | 95 | 20.5 | 109 | 80 | NW. | 0 | ...... | 44 |
| July | 107 | 89 | 98 | 17.8 | 112 | 86 | NW. | 0 | ...... | 19 |
| August | 107 | 88 | 98 | 19.0 | 114 | 83 | NW. | 0 | ...... | 20 |
| September | 101 | 81 | 91 | 20.0 | 106 | 80 | NW. | 0 | ...... | 11 |
| October | 94 | 76 | 85 | 17.2 | 99 | 71 | NW.-SW. | 0 | ...... | 21 |
| November | 79 | 64 | 72 | 15.0 | 89 | 56 | SW. | 2 | ...... | 19 |
| December | 62 | 53 | 57 | 9.8 | 69 | 50 | { SW.-SE. NW. } | 2 | ...... | 35 |

SHIRAZ.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 63.5 | 25.5 | 42.0 | 38 | 67 | 18 | NW. | 3 | ...... | 66 |
| February | 61.5 | 22.7 | 47.9 | 39 | 69 | 19 | NW.-SW. | 5 | ...... | 85 |
| March | 82.2 | 39.1 | 56.9 | 43 | 91 | 17 | NW.-W. | 0 | ...... | 75 |
| April | 85.1 | 43.4 | 67.6 | 42 | 97 | 33 | NW.-E. | 1 | ...... | 65 |
| May | 93.1 | 53.5 | 77.0 | 40 | 100 | 45 | NW.-E. | 4 | ...... | 54 |
| June | 101.6 | 61.5 | 86.2 | 40 | 107 | 55 | NW.-SW. | 0 | ...... | 49 |
| July | 105.1 | 65.7 | 89.6 | 40 | 112 | 59 | NW.-NE. | 0 | ...... | 46 |
| August | 103.9 | 64.7 | 85.8 | 39 | 110 | 58 | NW.-E. | 0 | ...... | 43 |
| September | 98.2 | 56.6 | 78.2 | 42 | 104 | 50 | N.-NE. | 0 | ...... | 48 |
| October | 91.7 | 48.2 | 64.7 | 43 | 97 | 38 | W.-E. | 0 | ...... | 42 |
| November | 82.7 | 40.0 | 55.5 | 42 | 82 | 32 | SW. | 7 | ...... | 64 |
| December | 73.5 | 32.4 | 45.8 | 41 | 70 | 27 | NW. | 1 | ...... | 77 |

DEHBID.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 35 | 20 | 28 | 15 | 39 | 1 | SW. | 8 | ...... | (?) |
| February | 42 | 23 | 32 | 19 | 47 | 15 | SW.-SE. | 7 | ...... | (?) |
| March | 53 | 30 | 41 | 23 | 63 | 15 | SW.-SE. | 3 | ...... | 6 |
| April | 59 | 35 | 47 | 24 | 69 | 25 | NE.-SE. | 4 | ...... | 43 |
| May | 69 | 40 | 54 | 29 | 78 | 34 | S.-SE. | 3 | ...... | 7 |
| June | 80 | 40 | 60 | 40 | 91 | 35 | SW.-SE. | 0 | ...... | 7 |
| July | 87 | 47 | 67 | 40 | 92 | 34 | S.-SE. | 0 | ...... | 18 |
| August | 83 | 47 | 65 | 36 | 93 | 36 | NW.-NE. | 1 | ...... | 23 |
| September | 70 | 40 | 55 | 30 | 74 | 33 | NW. | 0 | ...... | (?) |
| October | 62 | 33 | 47 | 29 | 68 | 22 | N.-W. | 0 | ...... | (?) |
| November | 46 | 24 | 35 | 22 | 58 | 19 | NW. | 4 | ...... | (?) |
| December | 39 | 22 | 31 | 17 | 50 | 10 | N.-NE. | 6 | ...... | (?) |

*Climatological tables for southern Asia*—Continued.

| Months. | Temperature. Mean maxima. | Mean minima. | Mean temperature. | Mean daily range. | Absolute maximum. | Absolute minimum. | Prevailing wind direction. | Number of days' rainfall. | Amount of rain and snow. | Mean humidity. |
|---|---|---|---|---|---|---|---|---|---|---|
| **ABADEH.** | | | | | | | | | | |
| | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | | | *In.* | *P. ct.* |
| January | (?) | 21.8 | 40.1 | 43 | (?) | 13 | NW. | 2 | ...... | 74 |
| February | 61.6 | 23.3 | 42.1 | 38 | 68 | 12 | NW. | 5 | ...... | 80 |
| March | 69.3 | 32.1 | 55.0 | 37 | 80 | 9 | ............ | 0 | ...... | 50 |
| April | 72.9 | 38.3 | 59.1 | 34 | 85 | 30 | NW. | 0 | ...... | 48 |
| May | 81.3 | 44.8 | 65.6 | 37 | 94 | 37 | NW.–SE. | 5 | ...... | 51 |
| June | 89.1 | 51.8 | 72.7 | 38 | 96 | 46 | NW.–SE. | 0 | ...... | 49 |
| July | 94.3 | 56.4 | 76.9 | 38 | 101 | 48 | NW.–NE. | 0 | ...... | 46 |
| August | 93.4 | 54.3 | 74.8 | 39 | 104 | 42 | NW. | 0 | ...... | 44 |
| September | 90.1 | 46.8 | 69.2 | 44 | 94 | 39 | NW. | 0 | ...... | 49 |
| October | 80.2 | 38.6 | 61.1 | 42 | 87 | 27 | NW. | 0 | ...... | 71 |
| November | 74.2 | 31.8 | 53.0 | 43 | 77 | 19 | NW. | 4 | ...... | 77 |
| December | 73.7 | 20.9 | 42.0 | 53 | 75 | 9 | NW.–SE. | 0 | ...... | 83 |
| **KASHAN.** | | | | | | | | | | |
| January | 41 | 29 | 35 | 12 | 48 | 24 | ............ | ...... | ...... | ...... |
| February | 47 | 33 | 40 | 14 | 54 | 29 | ............ | ...... | ...... | ...... |
| March | 60 | 45 | 53 | 15 | 66 | 32 | ............ | ...... | ...... | ...... |
| April | 71 | 49 | 60 | 22 | 76 | 38 | ............ | ...... | ...... | ...... |
| May | 80 | 59 | 69 | 21 | 86 | 53 | ............ | ...... | ...... | ...... |
| June | 89 | 69 | 79 | 20 | 95 | 60 | ............ | ...... | ...... | ...... |
| July | 93 | 73 | 83 | 20 | 99 | 70 | ............ | ...... | ...... | ...... |
| August | 90 | 70 | 80 | 20 | 90 | 65 | ............ | ...... | ...... | ...... |
| September | 88 | 61 | 72 | 22 | 81 | 55 | ............ | ...... | ...... | ...... |
| October | 69 | 51 | 60 | 18 | 72 | 45 | ............ | ...... | ...... | ...... |
| November | 54 | 45 | 49 | 19 | 57 | 34 | ............ | ...... | ...... | ...... |
| December | 43 | 33 | 38 | 10 | 42 | 26 | ............ | ...... | ...... | ...... |
| **KUM.** | | | | | | | | | | |
| January | 44 | 36 | 40 | 8 | 49 | 25 | W.–S. | 2 | ...... | ...... |
| February | 51 | 38 | 45 | 13 | 60 | 30 | SW. | 2 | ...... | ...... |
| March | 66 | 49 | 58 | 17 | 73 | 35 | W.–E. | 3 | ...... | ...... |
| April | 74 | 53 | 63 | 21 | 85 | 48 | W.–S. | 7 | ...... | ...... |
| May | 82 | 61 | 72 | 21 | 95 | 55 | W.–E. | 5 | ...... | ...... |
| June | 93 | 69 | 81 | 24 | 102 | 63 | W.–E. | 0 | ...... | ...... |
| July | 96 | 73 | 85 | 23 | 102 | 65 | E. | 0 | ...... | ...... |
| August | 92 | 71 | 81 | 21 | 98 | 61 | E. | 0 | ...... | ...... |
| September | 85 | 62 | 74 | 23 | 88 | 54 | S.–E | 0 | ...... | ...... |
| October | 71 | 54 | 62 | 17 | 83 | 45 | W.–S. | 4 | ...... | ...... |
| November | 58 | 46 | 52 | 12 | 66 | 35 | S.–W. | 4 | ...... | ...... |
| December | 49 | 38 | 44 | 11 | 52 | 35 | N.–E. | 1 | ...... | ...... |
| **MESCHED.** | | | | | | | | | | |
| January | 46.1 | 30.0 | 38.1 | 16.1 | 57 | 18 | NW. | 1 | 0.31 | ...... |
| February | 49.8 | 31.4 | 40.6 | 18.4 | 62 | 20 | NW. | 0 | 0.04 | ...... |
| March | 58.2 | 40.4 | 49.3 | 17.8 | 76 | 24 | SE. | 5 | 1.06 | ...... |
| April | 71.7 | 50.8 | 61.3 | 20.9 | 84 | 43 | SE. | 3 | 0.99 | ...... |
| May | 82.0 | 57.8 | 69.9 | 24.2 | 89 | 45 | NW. | 4 | 1.09 | ...... |
| June | ...... | ...... | ...... | ...... | ...... | ...... | ............ | ...... | ...... | ...... |
| July | ...... | ...... | ...... | ...... | ...... | ...... | ............ | ...... | ...... | ...... |
| August | 82.0 | 61.0 | 71.5 | 21.0 | 88 | 55 | SE. | 0 | 0.00 | ...... |
| September | 72.7 | 53.0 | 62.9 | 19.7 | 80 | 44 | NW. | 2 | 0.47 | ...... |
| October | 64.0 | 46.1 | 55.1 | 17.9 | 77 | 35 | NW. | 4 | 2.18 | ...... |
| November | ...... | ...... | ...... | ...... | ...... | ...... | ............ | 0 | ...... | ...... |
| December | 46.0 | 30.0 | 38.0 | 16.0 | 55 | 25 | NW. | 1 | 0.20 | ...... |

SECTION VIII.

# INSTRUMENTS AND METHODS OF INVESTIGATION.

## 13.—HISTORICAL SKETCH OF INSTRUMENTAL METEOROLOGY.

Prof. E. GERLAND.

The development of meteorological measuring instruments has taken the same course as the development of our physical knowledge in general—a small and unimportant progress in ancient and mediæval times, a more rapid and comprehensive development in the seventeenth, a retrogression in the eighteenth, and a new impulse in the nineteenth century.

In ancient and mediæval times there were employed in weather forecasting things which had not the slightest to do with the weather, as the constellations, the planets, or the phases of the moon. A need for meteorological measurements and for meteorological measuring instruments did not exist. Only to the observation of the winds, which indeed had not alone a meteorological interest, was any attention given. In ancient Athens the wind vane[1] had already been invented for this purpose; and we are informed that the names of the four cardinal points of the winds now generally used were introduced by the Emperor Charles the Great.[2]

Experimental work was not in favor at a time when scientific activity consisted in repetitions of the writings of Aristotle and presupposed an extraordinary independence of thought. It will therefore forever be to the renown of Cardinal Nicholas of Cusa that he was the first writer to give an empirical foundation for weather forecasting, since he

[1] In Athens, about the year 100 B. C., the Syrian Androndicus Cyrrhestes built the Tower of the Winds, which still stands. The sides of the octagonal building are oriented toward the principal points of the compass, and each bears a figure in bas-relief representing one of the winds. On the flat roof a Triton revolves as a wind vane and, with his staff directed downward, points to the personification of the prevailing wind. (See Stuart, The Antiquities of Athens, Vol. I, chap. 3; and Hellmann, "Die Anfänge der meteorologischen Beobachtungen u. Instrumente" in Himmel u. Erde, Vol II, Nos. 3 and 4.)

[2] The ancients designated mostly by separate names the winds which came from a direction between two cardinal points of the compass. As the historian of Charles the Great, Eginhart informs us it was the first Roman Emperor of Germany who first introduced the rational nomenclature of the winds. (See Hellmann in loc. cit.)

sought to determine future weather from the humidity of the air. His hygroscope consisted of a small bunch of wool which, being hung on the arms of a balance, increased in weight with the moisture and drew down the arm of the balance. Not much, indeed, had yet been done, but the middle of the fifteenth century, which saw the crusaders' activity, was the dawn of a more successful period of progress.

This light-bringing dawn appeared at the beginning of the seventeenth century; the resplendent Prometheus was Galileo. And not only in the master was the outbreaking flame powerful; it remained alive in his pupils. Indeed, these were in advance of their teacher, for they had not first, as he did, to divest themselves of the prevalently accepted scholastic conclusions; and so we see many discoveries made, which follow as evident consequences from the work of the master, which he had failed to recognize.[1] Of meteorological instruments, he gave us the thermometer; but for a number of others—the barometer, the ombrometer, and many hygrometers—we have to thank his followers. One of these, his biographer, Vivian, relates that during 1593 the Paduan professor, for purposes of comparison, sought to measure the temperature by means of an instrument consisting of a glass tube which had its upper end blown into a ball and closed, and its lower end dipped into a fluid. Then by careful heating, a part of the air was driven out of the ball, so that the liquid, mostly spirits, stood higher inside the tube than outside, and oscillated up and down with the changing temperature. Galileo made no measurements with this apparatus, which one can scarcely call a thermometer; the first who used it for such a purpose, after he had fitted it with a scale, was his friend Santorio, the professor of anatomy in Padua. His contemporaries, therefore, readily ascribed to him the discovery of the thermometer, while posterity has credited it to two other men of that day, to the Englishman Fludd, who placed his chief work in the mouth of one no less than the great lawgiver Moses himself,[2] and more persistently still to the tutor of the sons of the Emperor Ferdinand II, Drebbel of Alkmaar.[3]

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[1] See Gerland "Geschichte der Physik," Leipzig, 1872, pp. 116, 123.

[2] See Wohlwill, "Zur Geschichte und Verbreitung des Thermometers." Poggendorff's Annalen, 1865, vol. 124, p. 163. Burckhart, "Die Erfindung des Thermometers und seine Gestaltung im 17. Jahrhundert. Basel, 1867. C. Drebbel, "De natura elementorum." Hamburg, 1621. (Appeared first in 1604 in the Dutch language.) Fludd "Philosophia mosaica." Goudæ, 1638.

[3] In a small pamphlet concerning the thermometer, which appeared as number 470 of the collection of popular scientific contributions published by Virchow and Hollzendorff, Berlin, 1885 (20th series, on page 7), I expressed myself concerning this point in the following manner: "In the year 1624 Father Leurechon, a French physicist, published a book under the title "Recréations mathématiques," which responded to the needs of his time, since he introduced the method of teaching physics and mathematics by means of questions and their answers. This book aroused so much controversy that it was very soon translated into Dutch, German, English, and Latin. The German translation, published by Schwenter in 1636, and the English

For ourselves, did we not possess the weighty testimony of the friends of the great Florentine, Sagredos, Castellir, and Viviani, we could still not allow ourselves to favor the claims aroused for Fludd and Drebbel, for, according to their own evidence, both were dealing not with instruments for measuring the heat, but with a *perpetuum mobile.*

Fifteen years after the death of Galileo his surviving pupils came together at the *Accademia del Cimento*, under the patronage of Prince Leopold de Medici and his brothers, and under the protection of the Grand Duke Ferdinand II of Tuscany, with the view of carrying further by the experimental method the work left by their teacher. It is self-evident that the development of these views was bound up in an important way with the thermometer. They found an essentially improved instrument already at hand.

Perhaps, also, it may have been Santorio who affixed to the lower U-shaped tube the detached vessel used for holding the liquid in Galileo's apparatus. Since the inside of the attached lower ball communicated with the outer air through an opening, the inclosed air could change its volume with the temperature in the same way as in the original apparatus. Moreover, the new form of the instrument possessed the advantage that the glass tube could be affixed to a board to which at the same time the scale could be attached. It thereby gained greatly in portability and usefulness.

Before 1636, however, there were skillful glass blowers, who so fastened the ball and tube together that the inclosed liquid during the temperature change from winter to summer moved through the entire tube.[1]

The distance between these two extreme points the philosophers divided into degrees, the physicists into eight, the medical men into four times eight, similar to the custom of the present day. Already the investigators of that time had encountered the fact that observations made with similar instruments would not agree with each other. They soon learned one of the principal reasons for this. Galileo had, indeed, shown that the air had weight, but he had in no way drawn

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and Dutch as well, followed the original in the chapters treating of the thermometer * * * which, however, was not done in the Latin translation. Not, perhaps, because the author, the Lutheran theologian and Archdeacon Kaspar Ens in Lorch, a man who was frequently engaged in compiling manuscripts, intended to add new thoughts to the French original, the use of which he nowhere acknowledges, but he translates the superscription of one of the chapters in Leurechon's book "Du thermomètre, un instrument pour mesurer les degrez de chaleur ou de froidure qui sont en l'air," so as to read: "On the thermometer, or Drebbel instrument, by means of which the degrees of warmth or cold in the air are investigated." Thus Drebbel appeared in this book for the first time as discoverer of the thermometer, and it can be shown that from here the erroneous heading entered next into Dalencé's work, "Traittez des thermomètres," Amsterdam, 1688, whence it continuously spread.

[1] Schwenter: Deliciæ physico-mathematicæ, oder mathemat. und philosophische Erquickstunden, Nürnberg, MDCXXXVI, p. 456.

the conclusion from this that it might possibly exert a pressure on the earth's surface. Although he discarded Aristotle's theory of nature's horror of a vacuum, still he could find no better explanation for well known facts than to assume that solid bodies oppose a vacuum.[1] His pupil and successor, Torricelli, a year after his master's death, first inferred from the weight of the air the pressure which it must exert, and in accordance with his idea set up before his friend Viviani the first apparatus to show the pressure and its changes, which later received the name of barometer.[2] Many years afterwards it was brought out that Descartes had already reached this conclusion, and in a letter to his pupil, Renèri, on the 2d of June, 1631, had already given out the idea of the barometer,[3] still without its having been proven by trial.

That Galileo's instrument could only serve as a thermometer with unchanging pressure was now clear, and also that with stationary temperature it served to measure the pressure of the air. For this purpose, in fact, it was used by the burgomaster of Magdeburg, Otto von Guericke, under the name of *semper vivum* or *perpetuum mobile* and, in 1660, he had the joy of having the forecast of a storm based on the sudden fall of the barometric fluid actually fulfilled.[4]

The thermometer must therefore be freed from the influence of pressure if it is to fulfill the purpose for which it was created; and with this task the Grand Duke Ferdinand busied himself toward the middle of the seventeenth century. He attempted to solve the problem by means of closed glass balls which floated in a fluid with the same specific gravity at a given temperature. If he lowered the temperature the ball rose toward the surface; if he raised the temperature the ball sank.[5] In 1664, and ignorant of this experiment, de Sluse, Canon of Liége, thought of the same thing;[6] but it is evident that in this way observations of slowly changing temperature could not be made practicable even with many balls of different weight, and also that the temperature could not be determined for any given moment. A better solution of the question had already been imparted on the 1st of January, 1632, by the French physician Rey to Father Mersenne. He had merely reversed the apparatus of Galileo so that the expanding fluid itself became the substance of the thermometer.

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[1] Galileo: Discorsi e dimostrazioni matematiche intorno a due nuove scienze attenenti alla meccanica ed ai movimenti locali. Albèri: Les opere di Galilei, vol. 13. German by A. von Oettinger in Ostwald's Klassiker der exacten Naturwissenschaften, Nos. 11, 24, and 25. Leipzig, 1890–91. No. 11, p. 14, etc.

[2] Biedermann: Bericht über die Ausstellung wissenschaftlicher Apparate im South Kensington Museum zu London, 1876. London, 1877, p. 416.

[3] Gerland: Geschichte der Physik, p. 127. See Descartes, Œuvres, par V. Cousin. Paris, 1824. Vol. vi, p. 204.

[4] O. von Guericke: Experimenta nova (ut vocantur) Magdeburgica de vacuo spatio. Amstelodami, 1672. Lib. III, cap. XXII.

[5] Burckhardt, l. c., p. 34.

[6] Huygens: Œuvres complètes, publiées par la Société Hollandaise des Sciences. La Haye, 1893, Vol. V, p. 132.

This idea the Grand Duke carried out; and by heating the alcohol which partly filled the tube to the boiling point and then sealing it with the blowpipe, he gave to the thermometer the form which it retains to the present day. Afterwards this newer apparatus was called the Florentine, the earliest form, the Drebbel, or Belgian, thermometer.

The academy, therefore, possessed the thermometer and barometer in a thoroughly useful form, and showed its appreciation of the great value of both instruments by sending them to different places, especially to monasteries, with directions for use, and descriptions and also instructions to record wind direction, cloudiness,[1] and atmospheric humidity, which Torricelli had already, in 1646, sought to determine from the movement of the very hygroscopic hairs of the wild oats.[2]

Their example was followed by the Royal Society of Sciences of London, which came into life in 1663. This society distributed thermometers which Robert Hooke, then director of experiments, had prepared,[3] and directed that besides the temperature also the wind and rain be recorded.[4] About the same time, 1666, Boyle instituted observations of the humidity of the air[5] by means of the beard of the wild geranium (*Erodium moschatum*).

Such employment of the thermometer aroused in both these learned societies the desire to increase the sensitiveness of the instrument. The simplest method which presented itself was to enlarge the instrument. Since, however, it would in this way have attained an inconvenient and dangerous length, the Florentine glass artisans bent the tube into a neat helix.[6] Hooke lacked the necessary skill to accomplish

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[1] Burckhardt, l. c., p. 39.

[2] Monconys: Journal des Voyages. Lyon, 1665; Paris, 1695. German by Funker, 1697.

[3] Huygens, l. c., Vol. IV, p. 429, note 6 reads: "Dans la séance du 9 septembre, H. Oldenbourg annonça que Beale s'était offert pour observer les changements du temps et que celui-ci espérait faire participer à ce travail d'autres personnes en différents lieux du pays; il pria la Société Royale de lui faire parvenir quelques thermomètres identiques, pour les distribuer. L'Assemblée ordonna à l'opérateur, R. Hooke, de procurer une douzaine de ses thermomètres à esprit de vin qui seraient envoyés à Beale et dans différentes parties du monde." Oldenbourg was the secretary of the Royal Society; Beale, Rector of Yeovil (Somersetshire) and a member of the society from its foundation.

[4] Huygens l. c., Vol. V, p. 345: On May 1, 1665, Moray, the president of the Royal Society, after notifying Huygens of his intention of sending him a Hooke thermometer, wrote: "Maintenant si vous voulez auprès du thermomètre un tube plein de mercure, et faire des observations de temps en temps, des altérations qui arrivent à l'un et à l'autre, et en même temps remarquer s'il fait pluye, vent, etc." By tube filled with mercury is meant the barometer.

[5] See Hellmann, l. c., p. 15, where, however, the German name of the plant is erroneous.

[6] A beautifully made instrument of this description is still retained in the museum of Galileo in Florence. It is portrayed on page 70 of my report on the historical part of the international exhibit of scientific apparatus in London, in 1876, in A. W. Hoffmann's report on the scientific apparatus at the London International Exposition, 1876. Braunschweig, 1878.

this, so his thermometer grew to the very considerable length of from 2 to 3 feet.[1]

A greater difficulty was found in the task of making the different instruments comparable. At first arbitrary scales were given to the thermometer, as also to the barometer. The divisions were very neatly indicated on the glass tubes by the Florentines with small melted drops of white and black glass. Then by comparing them with a standard they could be made to give very satisfactory results.[2]

The measures of length now used were soon adopted for the barometer scale. As regards the comparability of the thermometer, it was recognized that if one could obtain fixed points on the scale, easily reestablished, and under all circumstances at invariable temperatures, one could be freed from the necessity of a standard instrument; and as this would make easy the reestablishment of a heat measurer at any place, therefore much trouble was taken to find such invariable temperatures. This proved itself by no means easy. The Florentines sought them in the temperature of ice and snow at the times of severest frost and in the temperature within the body of a freshly slaughtered animal; Fahrenheit, a glass artisan born in Amsterdam, used the temperature of a freezing mixture of ice, snow, and sal ammoniac, and that of a healthy man; La Hire believed, much later, in the unchangeableness of the temperatures in the open room of the Paris Observatory when it was freezing out of doors, and in that of the deepest cellars of that building.[3]

Finally, how far Hooke was from a true appreciation of the importance of this point is shown by the fact that he so little understood the proposal which Huygens[4] had already made in 1665 to the Royal Society to take the freezing and boiling points of water as fixed points that, contrary to his usual habit, he neglected to claim this as his own method.[5]

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[1]Huygens, l. c., Vol. V, p. 168.

[2]In the letters mentioned in the forgegoing reference Moray remarks explicitly: "Car c'est par l'épreuve de cecy que le Thermomètre qui sert pour le Tarif ou mesure des autres, a esté fait." That the Florentines used standard thermometers is proved by the fact that their thermometers compared with other Italian thermometers found in trade were reliable throughout. See Wolf: Experimenta Physica, oder "Allerhand nützliche Versuche." Halle, 1722, Part II, Chap. V, § 67.

[3]Lambert: "Pyrométrie." Augsburg, 1779, p. 29.

[4]Huygens, l. c., Vol. V, p. 188. The extremely important passage in question runs: "Il seroit bon de songer a une mesure universelle et déterminée du froid et du chaud; en faisant premièrement que la capacité de la boule eut une certaine proportion à celle du tuyau, et puis prenant pour commencement le degré de froid par lequel l'eau commence à geler, ou bien le degré de chaud de l'eau bouillante, afin que sans envoier de thermomètres l'on peut se communiquer les degrez du chaud et du froid qu'on auroit trouvé dans les expériences, et les consigner à la posterité." This passage is partially given by Momber in "Daniel Gabriel Fahrenheit, his Life and Works." Proceedings of the Natural History Society at Danzig, new series, Vol. VII, Pt. III, 1890.

[5]See my "Geschichte der Physik," p. 185, and my publication, "Briefwechsel Leibnizens und Huygens' mit Papin, nebst der Biographie Papins." Berlin, 1881.

The Florentines had, moreover, by this time determined the freezing point of water and accepted it as unchangeable, since it appears that they used this point for the control of their thermometers. This view Hooke did not accept. His researches had convinced him of the opposite. Notwithstanding all this, the perfect stability of the temperature of melting ice was first recognized in 1694 by Renaldini,[1] who had been a member of the Accademia del Cimento, which disbanded in 1667.

This learned society had not only busied itself with the thermometer and barometer, but all other meteorological measuring apparatus had profited by its activity. Santorio had already observed, in 1626, that catgut is shortened by the moisture in the air. Twisted cords therefore might be arranged in such a way that with changing atmosphere humidity they would twist and untwist and turn an indicator attached to them, an example of which one sees at present utilized in the so-called weather houses. The academicians, however, were more attracted by Folli da Poppis's observation that a strip of paper is lengthened by increasing humidity. They replaced the strips of paper by similarly acting strips of parchment, fastened them at both ends, after Da Poppis's example, loaded the middle with a weight, and estimated by the rise and fall of the latter the changes in the moisture contents of the air. The *mostra umidaria* of the Grand Duke gave more exact results. It consisted of a downward-pointing, cone-shaped receptacle of cork covered inside with pitch, outside with a thin metal plate, and bearing under its lower opening a downward-pointing, hollow glass cone. Placed on a tripod, this receptacle was filled with crushed ice, from which the melted water dropped into the cone and ran off through a spout fixed in the upper rim. Its outer surface being cooled to the temperature of melting ice, the moisture of the air condensed on it and dropped off into a measuring cylinder placed beneath.

Although Ferdinand gave away many of these instruments, they do not appear to have been much used for observation. With their help the academicians established the relatively greater moisture contents of the southwest wind.

The first rain gauge was constructed by Benedict Castelli,[2] who belonged to the circle of scholars and friends of Galileo, and died long before the founding of the society. It was a cylindrical glass vessel, in which the rain was caught during a measured time. This apparatus

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Huygens gave in the notes which he jotted down for his own use his opinion of Hooke in the following words: "Hookii ineptæ suspiciones, injuriæ, alias satis ingeniosi * * * Ipsis Anglis molestus Hookius. Verhandelingen der 1. Kasse van het Koninklyk Nederlandsche Instituut van Wetenschappen." Amsterdam, 1817, p. 165, etc.

[1] Renaldini: "Philosophia naturalis." Patavii, 1694, Vol. III, p. 276.

[2] Castelli: Della misura dell' acque correnti. (See Hellmann, l. c., p. 20.) As a result of observing a very heavy, long-continued rain at the time of very low water in the Lake of Perugia, Castelli was led to investigate how much the level of the lake was raised.

was improved by the Royal Society. Hooke, indeed, in 1670, made it self-registering.[1] Hooke had also brought out the pendulum anemometer several years previously (1667).

Although the Accademia del Cimento had thus devoted itself to the construction of the thermometer; yet at the cessation of its labors this instrument was not so serviceable that it could be used to determine the temperature with exactness, much less the thermal contents.

Therefore, when Papin, in 1681, wished to determine the temperature in his "digestor," placed over the fire, he did not take one of these instruments, but observed rather the time it took drops of water of the average size to evaporate when placed on top of the receptacle; the difficulty of placing a thermometer may have helped in his choice.[2] On the other hand, other experimenters sought to improve the thermometer. The researches of Newton[3] and Halley[4], in the years 1686 and 1688, which had for their purpose the determination of the boiling point of water, deserve scarcely the celebrity which the great names of their authors procured for them.

Halley also tested the question whether alcohol could not be profitably replaced by mercury, which appears to have been already used for this purpose in France[5], but came to the conclusion that the alcohol was preferable. More deserving of consideration was the proposition of Renaldini, in 1694, to construct a scale by the use of the temperatures of melting ice (not freezing water) and boiling water, by first sticking the thermometer in a mixture of one part boiling and nine parts ice-cold water, then in a mixture of two parts boiling and eight parts ice-cold water, and so forth, and noting the reading in each case.

As little attention as was accorded this excellent proposition of Renaldini was also given to the work of Amontons, a member of the Paris Academy of Science, published in 1703, although the results which he imparted were destined to lead to the progress which at last gave to the thermometer the necessary exactness as a measuring instrument.[6]

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[1] Birch: History of the Royal Society. 1756, III, p. 477.

[2] See Leibnizens und Huygens, Briefwechsel mit Papin, p. 19.

[3] Newton: Optics. Lib. III. Newtoni opera quae extant omnia Comm. Horseley. Londini, 1779-1785, Vol. IV, p. 223.

[4] Halley: An account of several experiments made to examine the nature of the expansion and contraction of fluids by heat and cold, in order to ascertain the divisions of the thermometer. Philosophical Transactions, London, 1693. No. 197, p. 650, etc.

[5] In the "Projet de la Compagnie des Sciences et des Arts" in Paris, which one finds in the posthumous papers of Huygens' (Œuvres complètes, Vol. IV, p. 326) are mentioned researches in which "Des thermomètres du vif argent" were used. The project probably belongs to the year 1663.

[6] Histoire de l'Académie Royale des Sciences, année 1703. Paris, 1705, p. 50. (See also my work in "Festschrift des Vereins für Naturkunde in Kassel, 1886;" and in "Zeitschrift für Instrumentenkunde." 1886, Vol. VIII.) Amontons criticised the thermometer scales used in his time, since he says: "Ainsi un degré de thermomètre

Proceeding on the assumption made by Newton that the phenomenon of heat was produced by æther oscillations, he came to the conclusion that the air expanded in proportion to the contained heat, and since he also rightly defined the zero point as the temperature at which the air possessed no further elasticity, he anticipated the law which is now call after Gay-Lussac, but which he himself ascribed to Charles. The experimental results of Amontons did not show the desirable accuracy, since the French scientist thought it was necessary to use the mean height of the barometer as the basis for the calculations in his researches with an air thermometer which did not differ greatly from the form still used. These incited Fahrenheit to his researches concerning the unchangeableness of the boiling point of water, the most valuable result of which was the knowledge of its dependence on the pressure.[1]

Since he then decided to take mercury as the thermometric substance, and proved by a special research that water can be cooled far below the melting point of ice, so that not the freezing point of water, but the melting point of ice is the true fixed point, he was, on account of his great skill in glass blowing, in a position to furnish thermometers which satisfied far-reaching claims to exactness and elegance. Indeed, they can very well compare with those made at present, as I convinced myself by a pair which I found in the collection of the physical cabinet of Leyden. I would have held this work as much more recent if it were not that there is a representation of one of these instruments to be found in Gravesand's *Physices Elementa Mathematica*, the third edition of which appeared in 1742. Therefore the scale of Fahrenheit is the oldest thermometer scale which has maintained itself. The distance between his two accepted fixed points, which I have already mentioned, he divided into 180 degrees, so that his zero point was placed in the middle. Possibly, in accordance with the advice of the astronomers in Rome, he later went from the lowest fixed point upward, but then divided the distance between his two fixed points into 96 degrees. Since he then found the freezing and boiling points at 32° and 212° of this scale, it was possible for him to use both in the construction of his excellent

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ne peut être comparé à aucun degré de chaleur, et n'en sçaurait être par conséquent la mesure." He held it as essential to introduce another temperature scale that should fulfill the following conditions: "Les degrés de chaleur, c'est à dire la quantité des pouces et des lignes en hauteur de mercure que la chaleur fait soutenir du ressort de l'air d'ou il parolt que l'extrême froid de ce Thermomètre seroit celui qui réduiroit l'air à ne soûtenir aucune charge par son ressort, ce qui serait un degré de froid beaucoup plus considérable que celui que nous tenons pour très-froid." Earlier attempts had, however, taught him "Que de masses inégales d'air chargées de poids égaux augmentoient également la force de leur ressort par des degrez de chaleur égaux." (See Histore, etc., 1702, p. 156.)

[1] Fahrenheit: Barometri novi descriptio. Philosophical Transactions, London, vol. 33, No. 385 VI. See also, Momber: Daniel Gabriel Fahrenheit, sein Leben und Wirken. Schriften der naturforschenden Gesellschaft zu Danzig, n. s., Vol. VII, No. 3, 1890.

thermometers. Moreover, he must have had a good method of purifying mercury, since he distilled it and thus overcame the difficulties which Papin found impossible in 1684, when endeavoring to construct a reliable barometer and to make it independent of the temperature, although the Royal Society, whose curator of experiments he then was, had furnished him the mercury.[1] In fact, Fahrenheit, according to the testimony of Wolf,[2] made a very reliable barometer, and by constructing thermometers for the determination of the boiling point, he also invented the hypsometer.[3]

The remaining meteorological instruments were not improved by Fahrenheit or his contemporaries, but were applied to the carrying on of continuous observations, as also was the recording rain gauge of Mariotte, invented in 1686,[4] and that of Boyles's pupil, Townley, invented in 1703.[5]

That the appropriate and helpful labors of Fahrenheit should be followed all too soon by a period in which all his improvements in the construction of the thermometer should be given up, in which the melting point of ice should again be replaced by the freezing point of water—mercury by alcohol, the cylindrical by the spherical bulb—indeed, that a return should be made to the thermometers of Hooke, many feet in length, finds its explanation, I regret to say, in the fact that the investigator who next after Fahrenheit made the thermometer a study was Antoine de Réaumur, as bad a physicist as he was a justly renowned zoologist.[6] How else could he have thought of making the attempt to carry on the expansion of the alcohol to the boiling point of water in an open tube, and since this proved impossible, mix it with water until it could be done? Since he believed he found by this questionable undertaking that in the rise of temperature from the freezing to the boiling point the alcohol expanded about 8 per cent, he marked the former 0° and the latter 80°; but the thermometers made by him were so miserable that at a later research one of them was found to be not 80°, but 64.3° at the boiling point. Indeed, Du Crest[7] sought to improve the method of construction of Réaumur, in that he made the thermometer air-tight, although he did not make a vacuum, and Celsius proposed to take 100 degrees instead of 80, marking the freezing point 100° and the boiling point 0°, which marking his coun-

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[1] Leibnizens und Huygens' Briefwechsel mit Papin, p. 23.

[2] Wolf: Relatio de novo barometrorum et thermometrorum concordantium Geneve. Acta Eruditorum. Lipsiæ, 1714, p. 380.

[3] Fahrenheit, Philosophical Transactions, vol. 33, No. 385 VI.

[4] Mariotte: Traité du mouvement des eaux et des autres corps fluides. Paris, 1686.

[5] Townley: A prospect of the weather, wind, height of the barometer, etc., 1703–4. Philosophical Transactions, London, 1705.

[6] De Réaumur: Mémoires de l'Académie des sciences, 1730.

[7] Du Crest: Recueil de pièces sur les thermomètres et baromètres, par l'auteur. d'un thermomètre universel. Bâle, 1757. See also Deluc: Recherches sur les modifications de l'atmosphère. Genève, 1772, p. 315.

tryman and colleague, Strömer, reversed,[1] but the comprehensive labors of Deluc at Geneva were needed to reintroduce the improvements of Fahrenheit, much to the advantage of science.

A happy accident saved the barometer from a similar degeneration. The observation of Picard that the mercury when shaken in the barometer chamber can, under certain circumstances, become luminous had long challenged explanation. In this connection the Parisian academician, Dufay, learned accidentally from a German glass blower that in his country barometers completely free from air were obtained by thorough boiling,[2] and believed that he had found a cause for the puzzling phenomenon. In this he was deceived, but since he published the new method used in Germany he thereby introduced the method of making barometers of a high degree of excellence.

In England about this time the problem of constructing maximum and minimum thermometers was actively taken up. Lord Charles Cavendish[3] first solved this question in 1757, and later in a similar way Magnus, in Berlin, for the geothermometer,[4] and Walferdin, in Paris, by the *metastatischen* thermometer.[5] Six attained the same end in a very pretty way by his thermometrograph,[6] which has been widely spread since a method of transporting has been learned and, at least in Germany, has almost displaced the thermometer of the Edinburgh professor, Rutherford.[7] The example of Watt's indicator then led to the construction of registering thermometers, for which purpose the metal thermometer was especially suited.

To the present century came the question whether the scale of the thermometer should be so reconstructed that the total amount of heat (thermal contents) could be read off.

Since it had been shown that the coefficient of expansion of gases has a fixed value, Regnault constructed air thermometers of different gases and tested their action.[8]

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[1] Poggendorff: Ueber die Celsius'sche Thermometerscala. Poggendorff's Annalen, vol. 157, p. 352.

[2] Dufay: Mémoire sur les baromètres lumineux. Histoire de l'Académie française des sciences, 1723, p. 295.

[3] Cavendish: On some thermometers for particular uses. Philosophical Transactions, 1757. Lord Charles Cavendish was the father of Lord Harry Cavendish, the discoverer of hydrogen.

[4] Magnus: Geothermometer und damit gemessene Temperatur des Bohrlochs zu Rüdersdorf. Poggendorff's Annalen, vols. 22 and 28, 1831 and 1833.

[5] Walferdin: Sur les thermomètres différentielles proposés par lui. Comptes Rendus, Paris, XIV, 1842.

[6] Six: Account of an improved thermometer. Philosophical Transactions, London, 1782; and the Construction and Use of a Thermometer for Showing the Extremes of Temperature in the Atmosphere During the Observer's Absence. London, 1794.

[7] Rutherford: A description of an improved thermometer. Transactions of the Royal Society of Edinburgh, Vol. III, 1794.

[8] Regnault: Relation des expériences, etc., pour déterminer les principales lois et les données numériques qui entrent dans le calcul des machines à vapeur. Mémoires de l'Academie française des sciences, Paris, vols. 21 and 26. 1847 and 1852.

Their agreement was good enough for moderate temperatures and where not too great exactness is demanded, so that the degrees of those air thermometers might be set down as proportional to the thermal contents of the air. After that, by comparative observations, it was easy to determine the value of the degrees of the mercury thermometer. Lord Kelvin (formerly Sir William Thomson) has, however, also described a way of determining an absolute temperature scale the degrees of which denote exactly equal amounts of heat.[1] The necessary calculations have been made and the highest utility to be derived from the readings of the thermometer attained.

To the labors of the Glass Technical Institute in Jena our thanks are chiefly due that the progress of the technique does not remain behind the theory. Varieties of glass have there been made for which the changes in the zero point after high temperatures, first observed by Despretz[2] in 1837, may be avoided.

The attempts which we meet in the second and third decades of our century to make the mercury barometer transportable were made unnecessary when the Florentine mechanic, Vidi, in 1848, invented the aneroid,[3] the idea of which Leibnitz had already outlined in 1697 in a letter to Papin.[4]

The researches concerning the capillary depression in the barometer, which Bravais had instituted in 1852[5] did not thereby lose their value, however, because the scale of the aneroid is calibrated by comparisons with the mercury barometer. The apparatus of Vidi, the aneroid, and the more recent metal barometer of Bourdon, with the vacuum chambers in the form of incomplete rings, are at present mostly, if not exclusively, utilized for altitude determinations.

The hygrometer also was more carefully constructed and arranged for greater convenience in handling. Such instruments with rods of whalebone cut perpendicular to the fiber, designed by Deluc,[6] are now only to be found in old collections. On the contrary, the stretched blond human hair of De Saussure[7] has shown itself very useful when carefully prepared and its readings frequently tested at the point of highest humidity. The bifilar suspension therewith has not up to the present time been successful. Out of many other hygrometers proposed and

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[1] W. Thompson: Philosophical Magazine, vol. 33, 1848, p. 316.

[2] Despretz: Observations sur le déplacement et sur les oscillations du zéro du thermomètre à mercure. Annales de Chimie et de Physique (1. ser.), vol. 64, p. 312.

[3] See Baromètre anéroïde. Poggendorff's Annalen, vol. 73, p. 620.

[4] On the 21st of June, 1697, Leibnitz wrote to Papin: "On me parle d'un baromètre portatif avec du mercure, je crois qu'on en pourrait faire sans mercure par une manière de souflet bien fermé ou à la façon d'une pompe. Leibnitzens und Huygens Briefwechsel mit Papin, p. 222.

[5] Bravais: Nouvelle table des dèpressions du mercure dans les tubes du baromètre. Annales de Chimie et de Physique, ser. 3, vol. 5, 1842.

[6] Deluc: Nouvelles idées sur la météorologie. 2 vols. Paris, 1787. Papers in the Philosophical Transactions and the Journal de Physique.

[7] De Saussure: Essai sur l'hygrométrie. Neufchâtel, 1783.

constructed only that invented by Daniell,[1] in 1820, in its improved form by Regnault,[2] in 1845, and the psychrometer constructed by August,[3] in 1825, have survived.

Finally, there belongs to our own century the attempt to measure the atmospheric electricity, which had first been qualitatively shown in the thunder clouds by Benjamin Franklin. Riess used for these researches an electroscope with a point or burning taper.[4] Actual measurements were, however, first obtained by Dellman with the Coulomb balance, which he had improved and made much more sensitive by attaching, instead of the measuring ball, a metal needle to the cocoanut fiber, or very fine silver wire, and using, in place of the stationary ball, metal strips, half of which acted from opposite sides, to deflect the ends of the needle.[5] At present, however, the Dellman electrometer is displaced by the much more exact and convenient apparatus of Lord Kelvin;[6] the measurement of atmospheric electricity has in recent times acquired a new importance.

Thus have all civilized nations successfully cooperated in the development of meteorological measuring instruments. That the North Americans were so little mentioned in this connection can not be wondered at, since that part of the history of the science which we had to describe had been mostly made before their appearance. Later investigators who in the future continue this history will be in an entirely different position, as shown by the very beautiful and important researches of recent times, and as shown by the calling of this congress in connection with the Columbian World's Fair.

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## 14.—THE RELATIVE MERITS OF ANEMOMETERS IN GENERAL USE.

W. H. Dines.

When I had the honor of being asked by your chairman to write a short paper on this subject, I agreed, little thinking of the difficulty I should find in fulfilling the task, or of my inability to do so satisfactorily.

Unfortunately, I am unable to read all the valuable memoirs on the subject that have been published in foreign languages, and also there

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[1] Daniell: On a new Hygrometer. Quarterly Journal of Science. Vols. VIII and IX, 1820.

[2] Regnault: Études sur l'hygrométrie. Annales de Chimie et de Physique, vol. 15, 1845.

[3] August: Ueber die Anwendung des Psychrometers zur Hygrometrie. Berlin, 1828.

[4] Riess: Lehre von der Reibungselectricität. 2 vols. Berlin, 1853.

[5] Dellmann: Ueber Oersted's Elektrometer und ein neues Instrument der Art. Poggendorff's Annalen, vol. 55, 1842.

[6] W. Thompson: Report of the British Association for the Advancement of Science for 1867, p. 489.

is in my case a personal difficulty about which I must ask your indulgence for saying a few words.

During recent years I have designed two anemometers, and hence it is difficult for me to be impartial. Neither of these instruments can be said to be in general use, and I do not propose to refer to them. Still, it is not possible to avoid mentioning certain faults from which they are free, and I must ask you to believe that I do not do so for the sake of praising my own work, but that I designed the instruments for the express purpose of avoiding the faults in question, which had previously become apparent to me.

Before discussing the merits of different anemometers, and our knowledge as to the correctness of their indications, there is one point which must be made clear.

Our only practical mode of trying an instrument, either of the pressure or velocity type, consists in moving it at various velocities through still or nearly still air. In use the instrument is fixed, and the air passes over it, and if there be any difference between these two cases, then the great majority of our observations and experiments are absolutely useless. Fortunately, however, there need be no hesitation in saying that the two cases are identical, and that the case of an anemometer moving in a straight line through still air is in every way identical with that of air moving with the same velocity over the fixed instrument. It would hardly be necessary to mention this point at all, except that the opposite view has been seriously put forward, and a factor determined, by what means I do not know, by which to change from one case to the other.

A simple assertion, made without proof, is of little value, but reference may be made to any standard book on dynamics or hydrodynamics, with the caution, however, that in some books the proposition is taken to be so self-evident that it is treated as an axiom, and assumed throughout without comment.

We are concerned simply with the motion of the air relative to the anemometer and with nothing else. As the thing to be measured is the motion of the air relative to the earth, the anemometer is fixed relative to the earth. It can not be said to be fixed in any other sense, because the earth itself is moving with a velocity so great that our strongest winds are hardly comparable with it. There are cases, however, in which anemometers in the form of air meters are used, and not fixed relative to the earth—in the measurement of the ventilation of a ship, for example, and in this case it has not been suggested that a correction is necessary because the ship itself, and therefore the anemometer, is moving. There is no need to multiply instances, but it may be said that if the supposed difference between the two cases did exist, then the method by which eclipses of the sun and moon are foretold years in advance, in fact, the whole application of dynamics to astronomical problems is founded on a false supposition, and the extreme improbability of such a conclusion is obvious.

It is very likely that steady motion of a fluid past a stationary obstacle can not be obtained, whereas steady motion of an obstacle through a fluid at rest is not a difficult matter to bring about.

Most cases of fluid motion with which we are acquainted are decidedly unsteady—the wind blows in gusts, seldom maintaining the same velocity for even a second, and water in flowing down a river generally shows some swirls and eddies. That the resistance to steady motion should not be the same as to unsteady motion of the same mean velocity is very probable indeed, and this may be the cause why experiments made in the two different ways have not given identical results. Undoubtedly this is the case with the Robinson anemometer, and it is not possible to obtain the value of its constants, when in use, by experiments in which its velocity relatively to the air is steady and uniform.

I propose to take the following six classes of instruments, and avoiding as far as possible the mention of any special anemometer, to point out the advantages and faults of each class as a whole.

| | | |
|---|---|---|
| I. | Robinson | Velocity instruments. |
| II. | Windmill | |
| III. | Pressure plate | Pressure instruments. |
| IV. | Tube | |
| V. | Bridled | |
| VI. | Pendulum | |

THE ROBINSON ANEMOMETER.

The great merit of this instrument is its extreme simplicity; the defects are, that different sizes do not register alike; that the factor by which the velocity of the cups must be multiplied to give the velocity of the wind is not constant, and that the effect of a gusty wind is not the same as of a steady wind of the same mean velocity.

No one is likely to deny the two first statements; but the value of the factor, and the manner in which it varies with different kinds of instruments, with different velocities, and with a gusty as opposed to a steady wind, are still matters of dispute.

In 1871, the Rev. Fenwick Stow compared seven different kinds of the Robinson anemometer and found no two agreed. The question naturally arose as to which, if any, were correct, and numerous experiments were made, mostly on whirling machines. These experiments, however, have not helped us much, because the whirling machine motion is uniform, and in that respect unlike the natural wind; and two anemometers, calibrated so as to agree on the machine, do not agree when exposed side by side in the open air. The whirling machine experiments, however, showed plainly that the factor 3 is too great for velocities above 20 miles per hour, especially for large instruments such as the English standard (Kew pattern), which has 9-inch cups on 24-inch arms.

If we could depend on these experiments there would be nothing for it but to give up the instrument entirely, for with the steady whirling machine motion the factor for 10 miles per hour is quite different from

the factor for 20 miles per hour. Ten miles per hour is about the average velocity, but the extreme velocities exceeding 30 miles are those to which most interest attaches, and it is most undesirable to use an instrument which can not be correct in both cases.

However, the whirling machine motion is uniform, and the natural wind is not, and this fact has a most important bearing on the action of the Robinson anemometer.

It has been proposed by Prof. Marvin to construct some apparatus by which an anemometer can be moved through the air with a rapidly varying velocity, but I do not know whether the proposal has been carried out. It would be a most interesting experiment, but when it has been made we shall not be certain that the variations of the wind have been accurately followed, and if it causes much alteration of the factor the proper value will still be a matter of doubt.

In my opinion, the Kew pattern factor is fairly constant for ordinary winds exceeding 10 miles per hour. It certainly is not constant for the artificial and uniform whirling machine motion, but that is quite a different matter. If the Kew pattern have a constant factor, it is certain, from open-air comparisons, that the factor of many of the numerous other patterns is not constant.

The extent to which the multiplicity of patterns has been carried is instanced by the following fact: Mr. Stow compared seven different kinds, excluding one with conical cups. I have tried six different kinds on a whirling machine, four out of those six differing from Mr. Stow's. Thus we have the means of indirectly comparing eleven kinds, but the Weather Bureau pattern does not agree with any one of these eleven.

Mr. Ferguson, however, is carrying out a most valuable series of comparisons at Blue Hill Observatory, the American and English standards being, with other kinds of anemometers, compared by exposure to the natural wind. When the result of these comparisons is known it may appear that Prof. Marvin's statement that the Weather Bureau instrument has a variable factor is quite in harmony with my belief that the Kew pattern factor is nearly constant for velocities above 10 miles per hour. Also, if the actual velocities obtained from the Kew pattern with factor 2.1, the value which my observations have led me to consider the most probable, and those from the Weather Bureau anemometer corrected by Prof. Marvin's table, should agree, it would be very good evidence for the correctness of both determinations.

From the preceding statement of our knowledge about the Robinson anemometer, it appears that the wind velocities which have been published in the past are greatly in excess of their proper value, and that in many cases it would be a matter of considerable time and trouble for any one to find out from them what the actual wind velocity has been. For example, during a hurricane in Mauritius last year, Mr. Meldrum states that during a few minutes the anemometer recorded a velocity of 104 miles per hour. Unfortunately, I do not know what

particular type of Robinson is in use at the Mauritius observatory, and therefore whether 10, 20, or 30 per cent should be deducted to give the most probable value. In this case, the required information would not be difficult to obtain, but in many cases it would be difficult, or even impossible.

This is undoubtedly the great objection to the Robinson anemometer; it is also one that can be obviated, and which, indeed, never would have arisen but for the unfortunate original mistake about the invariability of the factor 3.

Another and more serious objection is, that the factor of the smaller types is not constant, and this is not easy to get over.

Thirdly, it is probable that all these anemometers give a higher value for a gusty than for a relatively steady natural wind of the same mean velocity, but I do not think the difference is large enough to be of much importance.

If we are to retain the instrument as the usual velocity anemometer, the number of patterns made should be restricted to two or, at the most, three.

The constants of these patterns, if not already known, should be carefully determined and their wheel works arranged so that each indicates the actual motion of the air as nearly as possible, correctness at the higher velocities being considered of the most importance. If the instruments are constructed so that a percentage of the recorded amount has to be taken, there is always a doubt as to whether the correction has or has not been applied.

The great difficulty is to effect the change so as not to make the present uncertainty still worse than it is. On this ground there is much to be said for retaining the present erroneous system, but its absurdities are so very apparent. To continually quote wind velocities as given by the standard, and to say, in a certain gale, the velocity was of such and such a value, well knowing all the time that the said value is from 10 to 30 per cent too high, is not at all creditable to meteorologists. Still worse is the practice we have in England of comparing anemometers with the Kew standard and supplying a table of corrections worded "of the true amount," when we all know that the Kew standard (factor 3) is the most erroneous of all.

### THE WINDMILL ANEMOMETER.

This class may be subdivided into two, kinds—those in which the sails are flat, and those in which the sails are curved. All the instruments which belong to this class labor under the disadvantage of requring a vane to keep the axis, round which the sails turn, parallel to the direction of the wind. The vane alone is not of much consequence, but wind vanes during a gale are subject to most violent oscillations, and hence some method of damping the vane, without impairing its sensitiveness, is a very desirable adjunct.

The descriptions of these instruments do not, as a rule, go into detail

sufficiently to show to which class they belong, and the experiments which have been made with them, excepting with the very delicate kind so extensively used as air meters, seem to have been but few in number.

At the Kew Observatory, under the superintendence of the late Mr. Whipple, a whirling machine was erected for the express purpose of testing air meters. It was turned by hand, and the extreme velocity obtainable was from 20 to 30 miles per hour. In some cases the owners wished for trials to be made at still higher velocities. At that time I was carrying out some experiments for the Meteorological Council, and had the use of a whirling machine driven by steam and having an arm 30 feet long, on which a light instrument could be moved at a velocity of 70 miles per hour. Mr. Whipple tested some of the air meters on this machine at speeds up to 70 miles per hour and found that the variation of the factor was very trifling. In consequence of this, and more especially of his own numerous tests at Kew, Mr. Whipple's opinion of these instruments was entirely changed, and I know that he considered them to be most reliable.

I have tried anemometers of this kind with curved sails on the same machine, and found a variation not exceeding 3 per cent at speeds between 4 and 70 miles per hour.

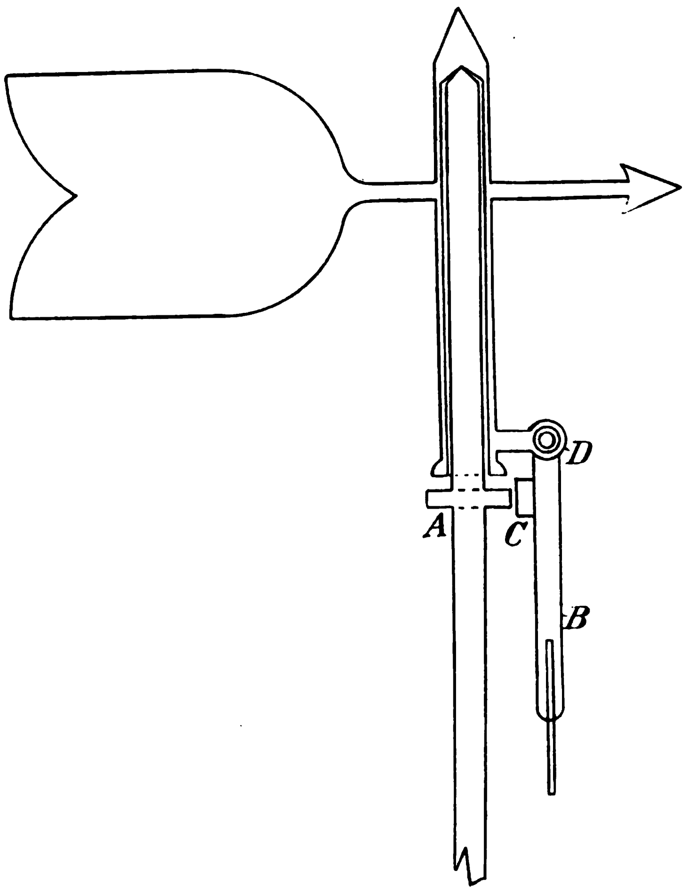
These results are remarkable, because the windmill anemometer was originally condemned on the ground that the velocity of the sails bore no fixed relation to that of the wind.

No doubt the Whewell anemometer, erected at Greenwich from 1843 to 1862, was much too small for the work it had to do; and the air meters so largely used in mines are not suitable for outdoor exposure. Still there is no difficulty whatever in making an anemometer of this kind, having the advantage of a nearly uniform factor and capable of being exposed to rain and snow without harm.

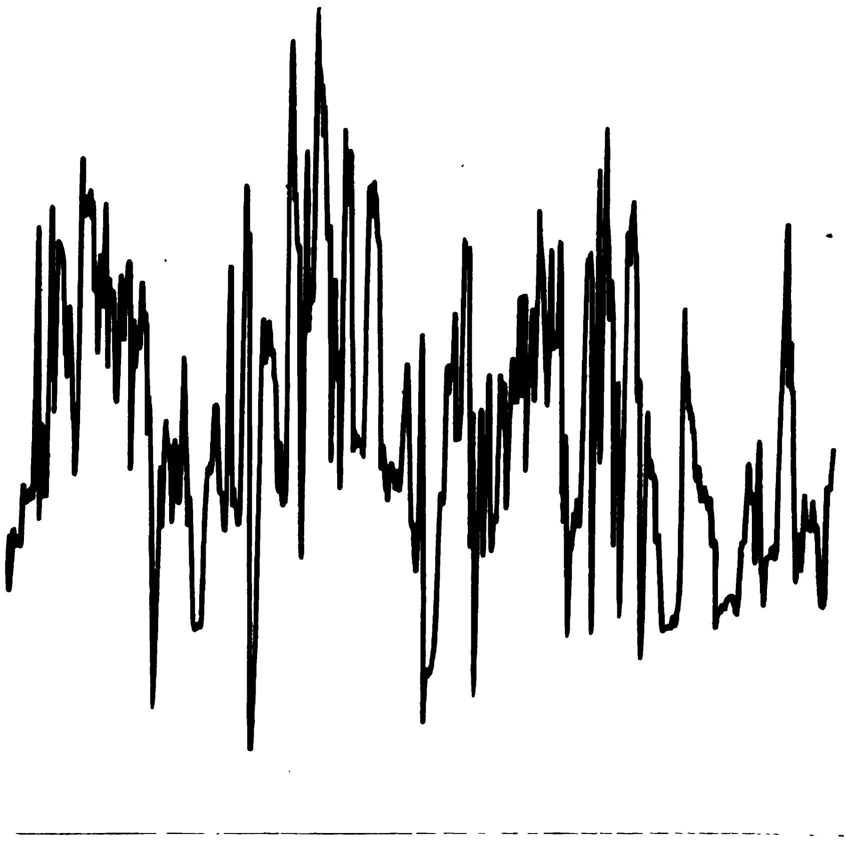
It is also worth noting that when an instrument of this class is tried out of doors at a fair velocity on a whirling machine it does not make much difference in the result whether the day be calm or not, but with a Robinson anemometer, the presence or absence of a little wind is a most important matter. Hence there is good reason to think that these instruments record the same mean velocity whether the motion be uniform or variable.

The question whether the sails should be flat or curved is not perhaps of much importance, provided that if the sails be flat they are of small extent when compared with their distance from the axis. For my part, I prefer a properly curved sail, because with it a large useful surface for the wind to act on may be obtained, and yet the instrument when turning freely need offer no appreciable resistance to the wind.

Like all velocity anemometers, these instruments require proper oiling and attention, otherwise their indications, especially for light winds, become unreliable.




ANEMOMETER. (DINES.)



ANEMOMETER TRACE. (DINES.) (GREENWICH, OCTOBER 15, 1891.)

The great objection to the use of this class of instruments is the necessity for a vane. This renders the anemometer less simple than the Robinson cups, and there is also the doubt whether any vane can keep the axis pointing to the wind. If it turn too easily the oscillations during strong winds are very violent, and if there is sufficient friction to damp these oscillations, it will not turn readily in light winds.

There are plenty of ways in which the damping may be effected, but, according to my experience, the double tail is not one of them. I have found the plan shown in the diagram (Pl. XXXVII) very simple and effectual. The fixed pivot has a metal ring, A, turned on it. The movable part has a short arm, B, hanging from it. This arm carries a block of hard wood, C, a short distance below the point D, at which it is hinged, and is so arranged that when it hangs freely under the action of gravity alone the block keeps just clear of the ring A. The bottom of the arm is flattened out into a sort of paddle upon which the wind presses. During light winds the block of wood and ring do not touch, but in a strong wind the pressure forces the block against the ring and thus applies a brake. The action is very effectual, because the pressure being proportional to the force of the wind, the brake is applied at the instant it is wanted and with just the requisite amount of force.

THE OSLER PLATE.

This is the instrument most commonly used for measuring the pressure, and is too well known to need description. The chief point of interest about this anemometer is the question as to whether the very high pressures which have been recorded by it are real or fictitious. It is impossible to prove the former conclusion, but it is possible to show that it is very unlikely and that the high pressures may be due to the instrument. The velocity, and therefore pressure, of the wind changes very suddenly and frequently, and hence, unless the moving parts of a pressure plate be of inappreciable mass, their momentum may carry them beyond their proper position. The following experiment shows this: Let a heavy sphere be suspended by a piece of string from a fixed point and its position of rest marked. Call this point A. The wind will drive the sphere from the position A. Suppose the wind westerly. The sphere will be mostly to the east of A, but it will oscillate, and, as a general rule during some of its oscillations, it will pass to the west of A. In a fairly open situation a westerly wind, however variable, never blows from the east, and hence the ball could only pass to the west of A in consequence of its own momentum. But if the momentum of the ball carries it too far on one side it must inevitably carry it too far on the other side, and thus in consequence of this momentum the maximum wind pressure recorded will certainly be too great. The pressure plate is not an exactly similar case, because with it there is always more or less friction; still the frictional resistance is small when

compared with the forces acting on the plate during a gale, and is not sufficient to check the oscillation.

There is a yet more important consideration in connection with these instruments. The wind pressure is applied to the plate exposed above the roof of the observatory, but the pencil which records the motion is generally in some room inside. The motion of the plate is of a most violent description, consisting of a series of oscillations and sudden jerks, and it does not seem possible to me to transmit this motion accurately to any distance. If the pencil be connected to the plate by light wires or chains it runs every risk of being jerked above or below its proper place, and a really rigid connection can not be made without enormously increasing the weight, and, therefore, the momentum and friction of the moving parts. The following fact is worth noting: In 1882, at the suggestion of Mr. Ellis, a light chain was substituted for the copper wire by which the pencil and plate at Greenwich were connected, and since that date the high pressures, which previously were not uncommon, have not occurred once. If this be only an accidental coincidence, it is a very curious one.

It appears from this that it is most desirable to have the clock and recording pencil close to the plate—in a hollow double vane at the back seems best. This does not do away with the momentum of the moving parts, but it reduces it to a minimum, and insures the pencil trace reproducing exactly the motion of the plate.

The accompanying trace (Pl. XXXVIII) taken on October 15, 1891, is appended to show how very frequent and great the variations of the wind are.

The paper moved at the unusual rate of 1½ inches in the minute, and the ordinate of the curve is arranged so that 1 inch may correspond to 10 miles per hour, 2 inches to 20 miles per hour, and so on. The average velocity of the wind which produced the trace was about 25 miles per hour.

It is obvious at a glance that the extreme pressures do not last, as a general rule, for so long as one second, and that there can be no certainty as to how nearly the pen follows the actual variations of the wind, and hence I think that while the records of a self-recording pressure plate are most valuable in giving the mean force of the wind for any short period, they are almost useless in giving any record of the absolute maximum.

In my opinion, the only way of obtaining reliable information as to the maximum pressure is to use a plate that can only move one way, and that can not come back from the position into which the wind has forced it until it is set by the observer. As the wind increases in average force, gusts of gradually increasing strength follow each other at short intervals. Each gust that is more powerful than any of its predecessors sends back the plate, but insomuch as no gust is very much stronger than the last, each time the plate goes back it only

moves a slight distance, and hence the final position attained can not be in any way due to the momentum of the moving parts.

Much has been written about the partial vacuum at the back of the plate, and also as to the best size. So far as the vacuum is concerned, my own experiments lead me to think that the shape at the back does not matter much, so long as whatever there is behind the plate is rigidly attached to it, but no fixed obstacle of any size ought to be allowed behind, or in fact anywhere near a pressure plate. The larger the plate the less proportionally is the pressure, but I do not consider the size to be of so much consequence as exact similarity between all the instruments in use.

### TUBE ANEMOMETER.

I am somewhat at a loss to know under what title to describe this class of instruments, as they are known by so many names. Under the above heading I include what Prof. Cleveland Abbe calls "Tubular Pressure" and "Suction" anemometers.

The principle on which they act is this:

The mouth of a tube which may be shaped in some special manner opens at a point in the outer air, where it is freely exposed to the wind. The wind in passing over the tube itself or some obstacle in connection with it causes a slight departure from the normal pressure of the air at the opening of the tube. This difference, whether it be an extra pressure or a suction, is transmitted through the tube to some point at which it is convenient to measure it, and the measure of this small difference shows the pressure and indirectly the velocity of the wind.

The great merit of these anemometers is that the action is transmitted through the tube for almost any distance without loss by friction and, since air is so light, without any appreciable momentum in the moving parts; hence the end of the tube may be in a well-exposed situation and the recording part indoors.

The objection is that the differences of pressure on which the action depends are exceedingly small, for light winds not more than a few hundredths of an inch of water, and that these differences must be determined by experiment for each kind of opening.

Fortunately, there is little difficulty in making the required experiment on a whirling machine, it being remembered that a correction is required on account of the centrifugal action upon the air in the tube which connects the opening at the end of the tube with the center of the machine.

This correction is given in inches of water pressure by the expression $\frac{12\ sv^2}{2g}$, when $s$ is the specific gravity of air and $v$ the velocity in feet per second of the opening at the end of the tube.

On the whirling machine the normal pressure is the air pressure at the time, and must exist at the center of the machine. It must not be assumed, however, that the pressure in the room in which the recording

apparatus is placed is necessarily the normal pressure when there is any wind. The pressure in the room depends on the form and positions of the openings from the room into the open air; if these openings are on the windward side the pressure is above the normal, and if on any of the other sides the pressure is below the normal. Opening or closing a door or window will alter the inside pressure. It is true that these alterations of pressure are very small, but so are the pressures on which the action of the tube anemometer depends. It has been remarked by some one that when a man has to walk a mile a few inches more or less is nothing, but that an inch or two added to the length of his nose is a good deal. When measuring the barometric height of about 30 inches of mercury an error of .01 inch is not so very great, but with a wind velocity of 10 miles per hour it is hardly possible to get differences of pressure from the tube anemometer amounting to .01 inch of mercury, and what is not a very large error in the one case may be from 50 to 70 per cent of the whole amount in the other.

However, it is beginning to be recognized that these pressure and suction effects of the wind in passing over a house do affect the barometers inside. Mr. Clayton states that during a gale at Blue Hill Observatory, Boston, opening or closing certain doors and windows may alter the height one-tenth of an inch, and we are all acquainted with the pumping of the barometer, which is doubtless due to this cause.

In connection with this subject, perhaps the following statement may be interesting. I have tried a great many different kinds of openings at the end of a tube, in hopes of finding one, such that when the wind passed over it it did not disturb the pressure inside. All my attempts were failures. Two partially succeeded, but they failed unless the wind met the opening at exactly the right angle. Well knowing how difficult it would be to insure this in practice, the attempt was given up. My trials were made on a whirling machine at a rate of about 70 miles an hour.

The difficulty may be avoided by using two tubes, each ending in a suitable opening exposed to the wind, one giving a pressure and one a suction. The difference of the pressure between the two gives the required velocity of the wind and is quite independent of the pressure in the room where the recording apparatus is fixed.

In my opinion, it is not desirable that either opening should be such that the pressure or suction produced depends on the exact angle at which the wind strikes the opening. The simple open tube used by Hagemann fails in this respect, for if the wind strikes the tube at an angle differing but very little from 90°, it greatly lessens the suction. There are many kinds of openings, however, which allow of variations of from 10° to 15° without harm.

The same difficulty occurs in registering the maximum pressure that has been previously noticed with the pressure plate, excepting that the connection between the head and the recording apparatus gives no

trouble. With this class of instrument it is very easy to prevent oscillation by contracting one of the tubes, or if liquid in a U or other shaped glass tube be used for a gauge, by contracting the bottom of the U.

This damps the oscillations and prevents too high a maximum being caused by the momentum of the moving liquid, but, on the other hand, if the damping is carried too far, the gust must last some time or else its full force will not be registered.

The great desideration is exact similarity between different instruments, and we have suffered so much in the past from the want of this in both the Robinson anemometer and the pressure plate that I venture to make the following suggestion:

All instruments of this class used for recording the maximum shall be damped to such an extent that when fixed in situ and the recording pen or index raised artificially to the position corresponding to 100 miles per hour they may take either 5 seconds or 5 minutes to fall to the position corresponding to 50 miles per hour.

I am at no pains to conceal my preference for this type of anemometer, having had one which has not required any oiling or attention since it was put up eighteen months ago. The reason for this preference will be best understood by those who have had to keep a well-exposed anemometer in good working order.

Apart, however, from the saving of trouble, it is a great advantage to have an instrument the head of which requires no attention, because in such a case a good exposure can be obtained, when otherwise the difficulty of getting at the anemometer for oiling would render this impossible.

## BRIDLED ANEMOMETERS.

These instruments differ from the pressure plate in that the part to which the force is applied moves in a circle instead of in a straight line, and also in that the pressure is not applied normally to the moving parts. Otherwise the principle involved is the same. The resistance, which gradually increases as the instrument is moved further from its zero position, may be produced by a spring, or by some arrangement which involves the lifting of a weight, and the possibility of too high a maximum being recorded, owing to the momentum, is the same as with other pressure anemometers.

So far as I know, the only instrument of this type which has had its constants experimentally determined is the one designed by Sir G. G. Stokes, and erected at Holyhead, England. The construction of this anemometer is such that no wire or flexible chain is used between the head and the recording pencil and paper, the connection between the two being perfectly rigid. The resistance is so arranged that the ordinate of the pencil trace is proportional to the square root of the pressure, and, therefore, to the velocity of the wind.

It is remarkable that the pressures recorded hardly ever exceed 30 pounds per square foot, although Holyhead is a most exposed and windy station. This is probably due to the absence of the wire or chain.

### PENDULUM ANEMOMETERS.

I am not in a position to say much about these instruments, never having had any actual experience with them; neither am I able in the time at my disposal to ascertain how their indications are recorded.

Probably the form constructed by Howlett in 1868, if a catch were provided so that the sphere could not swing back, would form a useful instrument for recording the maximum pressure. Plainly there is a double advantage in using a sphere instead of a plate, firstly, because it simplifies the anemometer by rendering a vane superfluous, and, secondly, because with a sphere the angle of incidence must always be the same.

In conclusion, I hope that the attention now being given to this subject may lead to improved results, and that in ten years' time the uncertainty which at present attaches itself to all questions of wind velocities or pressures may be a thing of the past.

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## 15.—RELATIVE MERITS OF THE VARIOUS TYPES OF REGISTERING MAXIMUM AND MINIMUM THERMOMETERS.

DANIEL DRAPER.

One of the earliest reports on the registration of heat is that of MM. Du Hamel, Du Monceau, and Tillet. These gentlemen were sent by the Government of France into the Province of Angoumois, in 1760 and 1761, for the purpose of destroying an insect which consumed the grain of that province. They effected their object in the manner related in the memoir for 1761, by exposing the affected grain, with the insects contained in it, in an oven, where the heat was sufficient to kill the insects without injuring the grain. This operation they performed at Rochefoucault, in a large oven. For economical reasons, they availed themselves of the heat remaining in the oven on the day after bread had been baked in it. Desiring to ascertain the temperature, they introduced a thermometer on the end of a shovel. On being withdrawn it indicated a degree of heat considerably above that of boiling water; but M. Tillet was convinced that the thermometer had fallen several degrees while the shovel was being drawn to the mouth of the oven. When he expressed his convictions on that head, a girl, one of the attendants on the oven, offered to enter and mark with a pencil the height at which the thermometer stood within the oven. M. Tillet, hesitating to accept this strange proposition, the girl smiled, and, entering the oven, marked the thermometer with a pencil. After staying two or three minutes the temperature thus registered was

nearly 260° F. M. Tillet began to express an anxiety for the safety of his female assistant, and urged her return. This female salamander, however, assuring him that she felt no inconvenience from her situation, remained there ten minutes longer, the thermometer standing at 288°, or 76° above the temperature of boiling water. When she came out of the oven her complexion, it is true, was considerably brightened, but her respiration was by no means laborious.

Turning now to matters of recent date, I shall confine my remarks in this paper to the instruments which have been used in the New York Meteorological Observatory for the past twenty-five years. They will be divided into two classes: First, registering instruments; second, self-recording instruments, the latter being subdivided into photographic and pencil instruments.

It does not come within the scope of this paper to discuss the date of the invention of the various kinds of thermometers, their construction or graduation, but simply their merits and demerits.

In 1868 there was in the observatory a Rutherford maximum and minimum thermometer. The construction of this instrument will be found described in any book on physics. Its merits are that it is easily read and adjusted for the next reading. Its demerits are that in the maximum thermometer the steel index on the top of the mercurial column in the course of a few years gets oxidized and becomes incased in the column of mercury, so that it ceases to register.

In the alcohol or minimum thermometer the greatest source of error is that in time the end of the column of alcohol evaporates and condenses in the upper end of the tube, thus shortening the column and making the instrument read several degrees too low. This defect may be corrected by holding the thermometer vertical with the bulb down and slowly heating the upper end of the tube with a lamp, so as to cause the alcohol to vaporize and condense on the column again.

Of this thermometer, and I may say of all index instruments, it is perhaps to be regarded as a defect that inexperienced or careless observers very often read the wrong end of the index, so that the readings are either several degrees too high or too low. For instance, in the mercurial maximum the end of the index nearest the column should be read for the correct maximum temperature, and not the end of the index farthest from the top of the mercurial column. In the alcohol minimum thermometer the end of the index nearest the top of the column gives the correct reading, while the end nearest the bulb would give a reading too low by several degrees. It is surprising how often the public make these mistakes in reading index registering thermometers.

There has been used in the observatory a Six's registering thermometer. Its construction and principle will be found explained in almost any work on meteorology or physics. It is not strictly a scientific instrument, but is at present by far the most popular maximum and

minimum thermometer on account of its open scale and easy adjustment Its demerits are that in course of time, if it is subjected to great fluctuations of temperature, the alcohol will creep past the mercury in the inverted syphon from one side of the syphon to the other. This error may easily be detected by noticing if the tops of the columns of mercury are both reading alike. If they are not, then the instrument is out of adjustment. Another and very serious source of error arises from the hair springs on the indexes losing their elasticity and not holding the indexes in the places where they were left by the columns of mercury. Strong winds shaking the instrument will often cause the indexes to slip down and thus give incorrect readings.

Mr. Casella, of London, has made several improvements in this thermometer, so that it is used with success for deep-sea temperatures.

In the observatory is a Negretti maximum thermometer constructed by James Green and numbered 2134. The peculiarity of this thermometer is that a contraction is made in the tube near the bulb. At the point of contraction the bore is so small that the mercury can not of itself return past it into the bulb. To reset, the instrument must be swung with some degree of force. It is at least an inconvenience if not a defect in this instrument, that it is liable to injury in resetting. The one in use at the observatory was destroyed by slipping out of the hand while being swung to reset it.

A Casella registering solar radiation thermometer, No. 13010, has been in use in the observatory since 1870. The special feature in this thermometer is that the column of mercury is broken by a small air bubble. If the instrument is not set perfectly level the reading during high winds will be unreliable, owing to the shaking of the column. It is also open to the same objection as a minimum alcohol thermometer, viz, that evaporation of mercury from the top of the column and its condensation in the upper end of the tube may take place. From this cause the instrument used in this observatory reads four degrees too low. I have tried in several ways to dislodge the mercury from the top of the tube, but have failed to succeed.

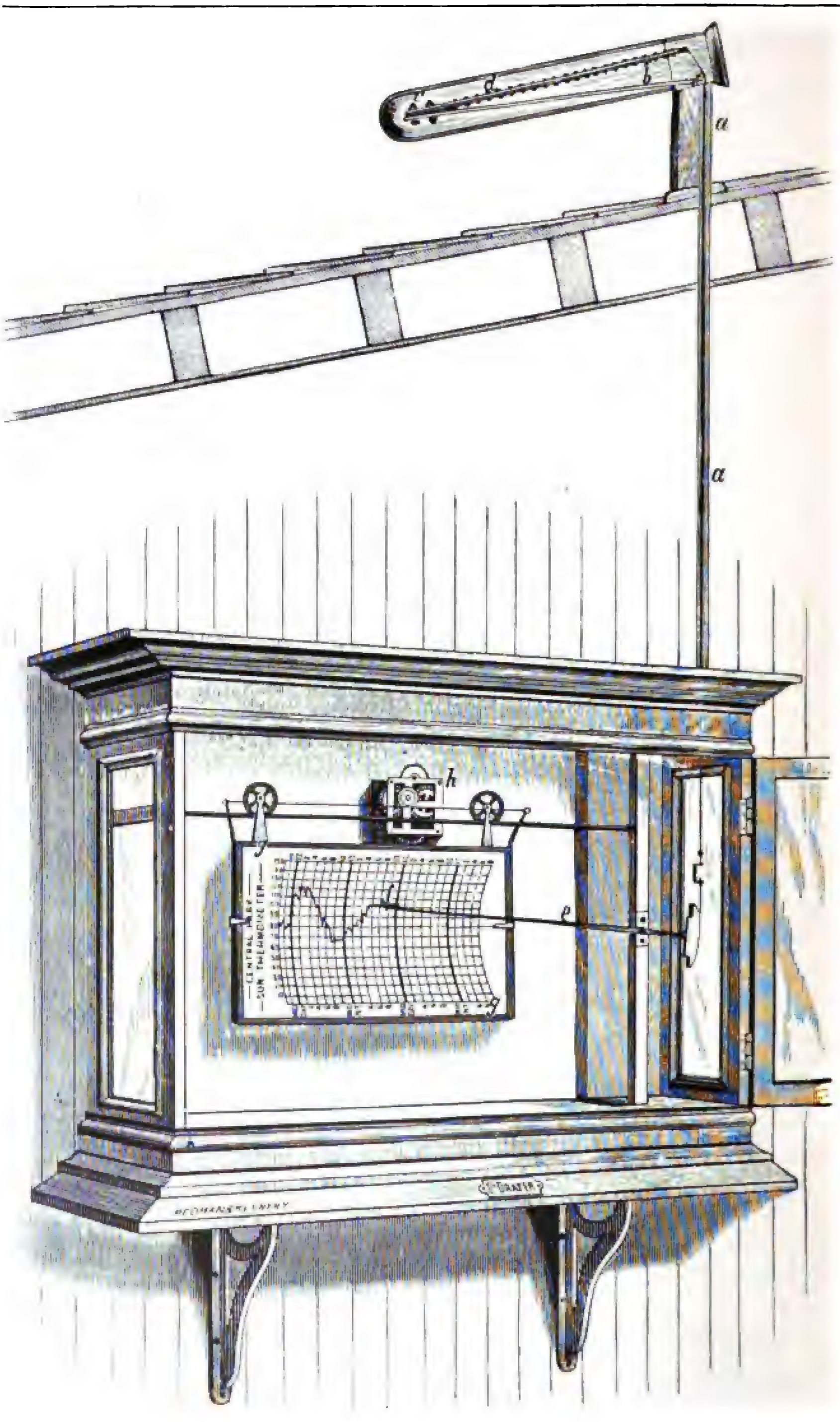
There are many other forms of maximum and minimum registering thermometers, but they have not been used in this observatory.

One of the great disadvantages connected with all registering thermometers is the difficulty of deciding at what time they should be read. This question was discussed at the International Meteorological Conference at Munich, held September, 1891. No definite conclusions were reached.

In all first-class observatories, however, this question does not occur. Being provided with self-recording thermometers, they have the exact time of maximum or minimum temperature recorded.

We have now come to the second division of our subject, that is, self-recording thermometers, with their merits and demerits.

Of this class of instrument, the first constructed was Beckley's




SELF-RECORDING SUN THERMOMETER. (DRAPER.)

photographic thermograph. It consists essentially of a sensitive sheet of photographic paper, on which falls a beam of artificial light, admitted through an air space in the column of mercury in the tube of the thermometer. This produces a record of the fluctuations of temperature. The sensitive sheet of paper is revolved once in twenty-four hours by means of suitable clockwork.

In 1868, on the establishment of the New York Meteorological Observatory, it was decided to make all the instruments self-recording. Beckley's photographic system was therefore adopted, with this improvement, that a dry collodion process was used instead of a sensitive sheet of paper. The impressions of the fluctuations of the mercury taken by means of an artificial light (such as a flame of gas) were received on the glass plate coated with a sensitive film, which, after development, could be read by means of a suitable scale, from fiducial lines on the photograph. The photographs were traced with a pantagraph on ruled sheets of paper. The collodion film was stripped off the glass on sheets of paper and preserved for future reference.

The disadvantage of all photographic processes is that the records can not be read until they are developed, and that the artificial light varies in intensity in hot or cold weather, so that a close watch has to be kept as to the sensitiveness of the films and great care taken in the development of the plate. On calm days the heat from the artificial light has quite a perceptible effect on the registered temperature. Other inconveniences may occur. On one occasion there was an explosion at the gas house, so that there was no gas at the observatory or in its immediate vicinity for three days.

The obvious disadvantages connected with photographic registration led to the construction of Father Secchi's wire thermometers, dry and wet.

By these a decided change in method was made. A pencil instrument was substituted for the photographic one. The construction of Father Secchi's thermometer was as follows: Two copper wires 30 feet long were suspended on the outside wall of a building. The lower ends of the copper wires were fastened permanently to the foundation wall of the building, the upper ends were attached to the short ends of two levers at the top of the wall, under the eaves. The long end of each lever carried an ink pencil, which recorded variations in the length of the copper wires on a ruled sheet of paper.

Of the two copper wires, one was covered with cotton and kept wet by water running down it. It was known as the wet bulb. The other was known as the dry bulb, or ordinary thermometer. The merit of this form of thermometer was that it could be read at any time. The demerit was that it had no fixed starting point in the scale, because the pencils were registering not merely the temperature of the atmosphere, but also the difference of expansion between a thick brick wall and a copper wire an eighth of an inch in diameter. Changes of

temperature affected the length of the wire very quickly, while their effect on the brick wall was slow, and, on account of the heat in the building, very irregular. Readings taken from this instrument had to be corrected by readings taken three times a day from the mercurial standard thermometer.

These defects in the Secchi wire thermometer led to the construction of a metallic bar thermometer, made by riveting together two strips of metal, the one of iron, the other of zinc. Zinc being more expansible than iron when there is a change of temperature, the bar is caused to bend. Its movement is transferred to a lever bearing on its long end an ink pencil. This records the variations of the bar due to changes of temperature on a ruled sheet of paper. The merit of this style of thermometer is that the readings may be taken at any time. It leaves a permanent record. The demerits are that if the bar, by accident, is bent to an excessive degree, the adjustment of the instrument is lost, and it has to be readjusted.

Furthermore, in case such an instrument is used as a wet-bulb thermometer, there will be a slow change in its adjustment owing to the rusting of the iron strip. This, of course, changes the amount of fluctuation in the bar.

This defect led to making the thermometer bars of vulcanite or hard rubber and brass riveted together. The merit of this thermometer bar is that it does not corrode, and it has a much greater movement than the iron and zinc bar. Its demerit is that if the temperature exceeds 160° F. the vulcanite softens and takes a set different from that at which it was graduated.

In all self-recording wet-bulb thermometers, both photographic and pencil, there are several very serious defects. One is the freezing in its tank of the water that keeps the thermometer moist; another is that the blowing of the wind, causing increased evaporation, makes the instrument record a temperature lower on a windy than on a calm day. It has often been noticed that when the dry bulb reads 32 degrees and the water in the wet-bulb tank begins to freeze, there is for several minutes an abrupt rise of temperature on the wet bulb record of three or four degrees of temperature. When first observed this was supposed to be due to the pressure of the water freezing in the muslin cloth around the bulb of the mercurial thermometer. But after the introduction of the metallic bar this same effect was observed. The phenomenon is undoubtedly due to the liberation of latent heat from the conversion of water into ice.

The demerits of the wet-bulb thermometer have led to the construction of a self-recording hygrometer which gives in cold, and I may say hot, weather, a much more reliable indication of moisture than the wet-bulb thermometer. De Saussure hygrometers have been very unjustly condemned because they have not been properly made and graduated. A discussion of hygrometers, however, does not come within the province of this paper, and I return to my subject.

The above self-recording thermometers are daily instruments—that is, their clocks have to be wound up and new sheets of ruled paper put on the instrument each day.

For public use the need of a simple self-recording thermometer has long been felt. One is now made in which the sheet of paper is changed once a week. The thermometer bars are made of brass and iron soldered together. These thermometers are made not only for meteorological observations, but also for business purposes. They register temperatures as high as 270° F., which are required in drying kilns. It may be of interest to remark that when the first one of these high-grade thermometers was put into a drying kiln with wheat, when the wheat was supposed to be dry and the kiln was opened, not only was the wheat scorched, but parts of the thermometer clock were melted and the paper chart of the instrument was scorched brown. These Draper self-recording dial thermometers have now attached to them an electric alarm, which can be set to sound when any maximum or minimum degree of temperature may be reached. Grain, lumber, etc., are sold by merchants whose kilns are provided with such instruments with an accompanying thermometer chart showing the number of hours during which and the degrees of temperature at which the articles sold have been dried.

For several years the telethermometric system has been used in the observatory with very good results. It is an electric apparatus, consisting of two portions; one, the transmitter with its thermostat, being kept in the place where the temperature is to be ascertained; the other, or receiver, being in the office or place at a distance where the temperature is to be recorded.

The merit of this system is that it accurately records full degrees of temperature of places difficult of access. Its demerit is the liability to derangement by atmospheric electricity or thunderstorms. Twice in three years the insulation of the magnets of this instrument used in the observatory was destroyed.

There is another self recording thermometer known as the "Richard thermograph." It is made in Paris, France. Its thermostat consists of a short curved flat brass tube filled with alcohol. With changes of temperature the brass tube either straightens or curves more. It is a small, portable instrument for recording ordinary temperatures.

At the present time experiments are being made in the observatory with a new self-recording air thermometer. The method employed is the introduction of a given amount of dry air into the upper part of a Draper self-recording barometer. The principle is that the difference between the readings of such a self-recording barometer with and without air is a measure of the expansion of the air by temperature.

So far nearly all of this discussion has been on self-recording thermometers in the shade. It now becomes necessary to speak of sunshine instruments.

The sun, being the source from which the earth derives its heat, is

the governing cause not only of the seasonal changes, but also of all minor meteorological effects, such as rain and the growth of vegetation. Hence sunshine observations have large practical importance.

Continuous sunshine observations are attempted in some observatories with the Campbell-Stokes sunshine recorder. This instrument consists of a glass sphere, which acts as a burning lens. In its focus and partially encircling the lens is a strip of ruled and prepared millboard, held in position by a suitable semicircular frame, fastened to the same base as the burning lens. According to the intensity of the heat of the sun a track is scorched or burnt in the millboard. If the day is overcast no burning takes place. Observations with this instrument are not altogether satisfactory.

In the New York Meteorological Observatory for the past twenty years sunshine observations have been taken with a Draper self-recording sun thermometer. It gives in Fahrenheit degrees not only the maximum temperature, but the diminution of the intensity of heat as caused by mist or clouds passing between the sun and the instrument. It may be of interest to remark that in the partial solar eclipse of March 16, 1885, at the beginning of the eclipse this instrument recorded 92°, at the middle 69°, at the end (2.50 p. m.) 82°, while the thermometer in the shade remained throughout the eclipse constant at 32°. In this eclipse one third of the sun was covered.

The construction of the Draper self-recording sun thermometer depends on the same principle as the dry-bulb thermometer, except that the metallic bar is inclosed in a glass shade four inches in diameter and twenty inches long, mounted several feet above the roof of the observatory and exposed to the direct rays of the sun. There is no vacuum in the glass shade; it only serves to keep the wind and rain from the bar. The bar is connected by a wire to a lever multiplying four times. On the long end of the lever is an ink pencil that records on a ruled paper the fluctuations of the bar caused by changes of temperature. On a clear moonlight night this instrument will record temperatures several degrees lower than the thermometer in the shade or louvre window, this louvre reading being due to radiation into space. (Pl. XXXIX.)

In conclusion, I beg to observe how strangely slow the advance in meteorology has been. The thermometer was invented by Sanctorio about 1624, but in his hands it was only a crude, imperfect instrument. We saw how, in the French experiment at Rochefoucault, in 1761, a young woman volunteered to enter the oven and mark the maximum degree of heat. In the year 1781, one hundred and fifty-seven years after Sanctorio's invention, comes the introduction of Six's registering maximum and minimum thermometer, while immediately following this period several forms of registering thermometers were devised. The next great advance in the measurement of temperature did not come until the introduction of the Beckley self-recording photographic ther-

mometer about the year 1856. In 1873, or seventeen years later, there were constructed in the New York Meteorological Observatory a pair of self-recording metallic thermometers, dry and wet bulbs, and also the self-recording sun thermometer.

Therefore, from the first inception of the thermometer by Sanctorio, in 1624, to the invention of the Draper self-recording pencil thermometer at this observatory in 1873, the lengthy period elapsed of two hundred and sixty years.

Before closing this discussion, I venture to draw attention to the close relation there is between the continuous recorded temperature, taken by Draper's self-recording sun thermometer, and the time of flowering of the *Forsythia Viridissima*, cherry and apple trees, during the past twenty years. As time and space are limited, let me select the last five years and give the results in the following table:

*Table showing the time and number of hour-degrees between the latest date in the spring when a temperature of 40° was recorded and the date of the flowering of the Forsythia Viridissima, cherry, and apple trees, for the past five years.*

FORSYTHIA.

| Year. | Date of last 40°. | Date of flowering. | Number of days. | Number of hour-degrees. | Average number of hour-degrees in a day. |
|---|---|---|---|---|---|
| 1889 | Apr. 8 | Apr. 15 | 8 | 12,493 | 1,562 |
| 1890 | Apr. 7 | Apr. 14 | 8 | 12,188 | 1.523 |
| 1891 | Apr. 10 | Apr. 18 | 9 | 12,562 | 1,396 |
| 1892 | Apr. 15 | Apr. 22 | 8 | 12,096 | 1,512 |
| 1893 | Apr. 21 | Apr. 28 | 8 | 11,651 | 1,456 |
| Mean for five years | | | 8 | 12,198 | 1,489 |

CHERRY.

| Year. | Date of last 40°. | Date of flowering. | Number of days. | Number of hour-degrees. | Average number of hour-degrees in a day. |
|---|---|---|---|---|---|
| 1889 | Apr. 8 | Apr. 22 | 15 | 23,289 | 1,552 |
| 1890 | Apr. 7 | Apr. 18 | 12 | 18,821 | 1,568 |
| 1891 | Apr. 10 | Apr. 23 | 14 | 20,687 | 1,477 |
| 1892 | Apr. 15 | (a) | (a) | (a) | (a) |
| 1893 | Apr. 21 | May 6 | 16 | 23,118 | 1,444 |
| Mean for four years | | | 14 | 21,478 | 1,519 |

a Not taken.

APPLE.

| Year. | Date of last 40°. | Date of flowering. | Number of days. | Number of hour-degrees. | Average number of hour-degrees in a day. |
|---|---|---|---|---|---|
| 1889 | Apr. 8 | May 7 | 30 | 49,413 | 1,647 |
| 1890 | Apr. 7 | May 6 | 30 | 47,973 | 1,599 |
| 1891 | Apr. 10 | May 8 | 29 | 44,175 | 1,524 |
| 1892 | Apr. 15 | May 13 | 29 | 48,277 | 1,664 |
| 1893 | Apr. 21 | May 20 | 30 | 48,357 | 1,611 |
| Mean for five years | | | 29 | 47,639 | 1,609 |

On comparing the different years with one another, it will be seen that the interval between the date when for the last time the temperature was 40° for several hours to the date of the flowering of the *Forsythia* was eight days, and there were during this interval about 12,198

hour-degrees of heat by the sun thermometer, making an average of 1,489 hour-degrees of heat for each day. In the case of the cherry the interval from the last 40° of temperature to the date of flowering was about fourteen days, or 21,478 hour-degrees of heat. In the case of the apple tree there was on an average twenty-nine days, or 47,639 hour-degrees of heat. By the table it will also be seen that while in 1890 the last 40° occurred on April 7, in the present year (1893) it occurred on April 21, or fourteen days later, showing the season to be two weeks later. Correspondingly the date of the flowering both in the case of the *Forsythia* and apple is fourteen days later, while the cherry was eighteen days later. From this table it becomes evident that if one should note the time of the flowering of the *Forsythia*, he could predict almost to a day the flowering of the cherry or apple. It would be not only interesting but valuable to know if these conditions hold good for all plants and trees, and also if the flow of sap and ripening of fruit requires a given number of hour-degrees of heat for each variety. These, however, are questions that belong to agricultural colleges situated in the country, and not to a meteorological observatory situated in the center of New York City.

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## 16.—ON THE CONSTRUCTION OF REGISTERING AIR THERMOMETERS, TO REPLACE THE ORDINARY ALCOHOL AND MERCURIAL THERMOMETERS.

A. SPRUNG.

With the sole exception of the barometer, all meteorological instruments must be exposed, as freely as possible, to the direct influenee of the weather. This circumstance is a material obstacle in the conversion of these instruments into self-registering apparatus, especially if a rather high degree of accuracy is demanded.

A clock exposed to all temperature changes between — 30° C. and + 35° C., and not infrequently to an increase of humidity up to 100 per cent, can not be expected to keep as good time as a clock kept in a dry place and at a uniform temperature. Another difficulty arises from the fact that the register sheets of all such apparatus are made of paper, which will, according to my experiments, considerably change its dimensions under the influence of moisture, even if it has been saturated with oil.

It follows, therefore, that a good meteorological self-registering apparatus must consist of two separate parts, the receiving instrument and the registering apparatus proper, which latter must be set up in a room that can be heated. This requirement is best met by using the electric current for establishing reciprocal relations between the two parts of the apparatus. But the peculiarities of the primary apparatus in question do not always admit of the use of this convenient medium.

Light may sometimes be used in place of it; but then the registration must be done photographically, which involves many inconveniences.

Another expedient is the elastic force of the air, which is transferred with the velocity of sound, in a narrow tube, and of which method the pneumatic bell is an example. A serious drawback to this method is the fact that a change in the temperature of the column of air will also change its elastic force, if the column is hermetically shut off. But this may be avoided. For this purpose a large supply of compressed air is necessary, which flows continuously through a fine opening, so that the connecting transfer tube is in communication with the atmosphere. The application of this method is relatively simple in some few cases, as for instance in a water gauge, but on the whole it is too complicated to come into general use.

The transfer methods outlined in the foregoing, and also some others, I took into consideration when it became a question of devising an unobjectionable apparatus for registering the temperature of the air. My thermobarograph,[1] it should be said, in so far no longer meets the latest requirements, as it is an accepted fact that the temperature of the air can only be determined in an absolutely certain manner by means of a powerfully aspirated thermometer. The principle of aspiration must, therefore, be also extended to self-registering thermometers; and this necessity materially increases the difficulty in designing the apparatus.

As is known, the first attempt in this direction has already been made by the inventor of the aspiration psychrometer, Dr. Assmann.[2] For the fundamental apparatus Assmann used the alcohol Bourdon tube, introduced by Richard Frères; but at the same time he dispensed with the local separation of the two parts of the apparatus, which is one of the conditions insisted upon by me in the foregoing remarks.

It might seem that this separation could be accomplished, in a measure, by simply connecting the Bourdon tube with the registering pen by means of a fine steel wire; but this is not done so easily, because the thermal changes in the length of the transferring wire would be much greater than the movements of the free end of the tube. A method of compensation might be applied here, however; a second identical wire could be stretched immediately alongside of the first one, with its free end not movable with the Bourdon tube, but absolutely stationary. On both wires any convenient body might be suspended, which, with mere changes in the temperature of the wires, would only go through translatory motions; while every change in the temperature of the Bourdon tube alone would only produce an angular motion. The translatory motion would have no disturbing effect if a mirror of sufficient length were fastened to the suspended body, which

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[1] Zeitschrift für Instrumentenkunde, VI, 1886, p. 189.

[2] Die Aspirations-Meteorographen in den Urania-Säulen. Das Wetter, Madgeburg, IX, 1892, p. 141.

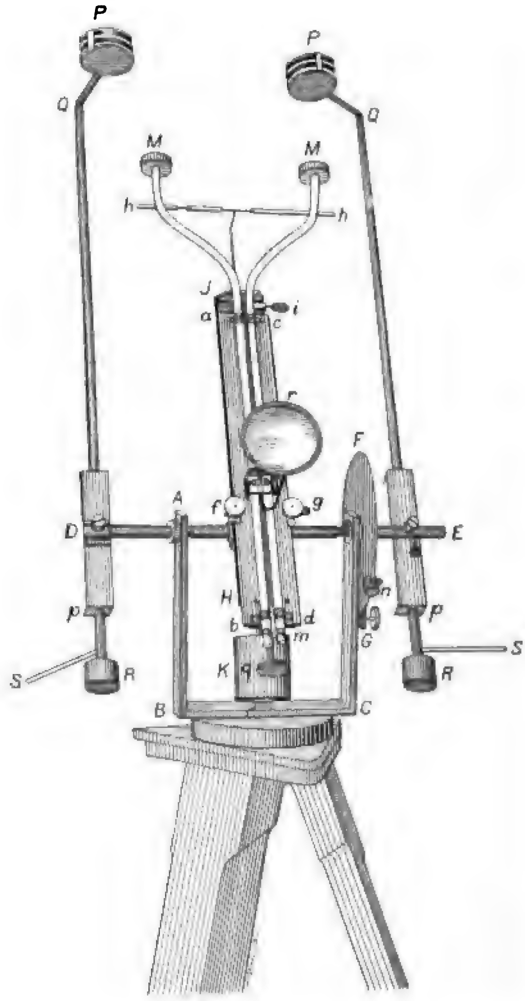
would then admit of the photographic registering of the angular motion in the usual manner. The transformation of what was originally a purely mechanical process into a photographic one can not, however, be called a specially convenient or satisfactory method.

Everything considered, I feel disposed always to revert again to the proposition which I made twelve years ago in the Zeitschrift für Instrumentenkunde, Vol. I, pp. 358–360. The subject of that memoir is "Die erste Form des registrirenden Luft-Thermometers"—the first form of self-registering air thermometer—the distinguishing feature of which is that it aims at the application of a *constant* volume of air. In this apparatus a true siphon barometer serves as manometer, whose shorter branch communicates with the air chamber by means of a narrow metallic tube. The atmosphere is therefore entirely cut off from this system, so that all disturbing effects due to variations of pressure are excluded in advance.

But the most material advantage gained by this form of construction lies in the fact that the mercury in the short branch of the siphon barometer is always maintained at the same level in spite of all changes of atmospheric pressure or temperature. The quantity of air over the mercury (which, be it remembered, is exposed to temperatures different from that of the vessel) needs, therefore, to be very small, and a corresponding reduction can be made in the capacity of the air vessel. While in a thermograph with open manometer the air vessel must have a capacity of several liters (about 300 c. c.), it can be reduced to 200 or 100 c. c. by using a constant volume of air; and in this manner we come to a vessel small enough to be readily ventilated in accordance with Assman's method.

Concerning the realization of this idea, I will only add the following: In the original proposition, as published in the Zeitschrift für Instrumentenkunde, an electrical contact between platinum and mercury, *inside* of the hermetically closed manometer, was provided for by way of example. Since then, however, an *outside* contrivance has been devised by which this contact can be made in precisely the same manner as in the thoroughly approved contact used in my sliding-weight barograph.

The distance between the air vessel and the registering apparatus is here assumed to be about 10 m.; and in an instrument constructed as here proposed this distance had best not be exceeded. For greater distances electricity would have to be applied; but how? That is the great and manifestly difficult question.




THE ACTINOMETER. (SCHWOLSON.)

## 17.—OBSERVATIONS OF SOLAR RADIATION—HOW BEST MADE AND COMPILED.

O. SCHWOLSON.

I have occupied myself with the interesting and important questions of actinometry for nearly three years and have presented the results of my studies in two dissertations: "Ueber den gegenwärtigen Zustand der Actinometrie" (Repertorium für Meteorologie, XV, No. 1) and "Actinometrische Untersuchungen zur Construction eines Pyrheliometers und eines Actinometers" (Repertorium für Meteorologie, XVI, No. 5). My labors are not yet completed and I hope to publish further results later on.

In the first paper I have studied the methods heretofore proposed for the measure of solar radiation, and have come to the conclusion that but one of these methods held out the possibility of obtaining either a relative or absolute measure the accuracy of which could be satisfactorily known.

I have specially investigated the known instruments of Pouillet, Crova, Violle, and Arago-Davy, and tested them theoretically as well as experimentally. The actinometer of Violle had already been investigated by S. P. Langley, one of the most renowned living meteorologists. I recognize the genius and incomparable art of experimenting of this great American scientist, although I have come to the conclusion that the apparatus is not suitable to serve for actinometric purposes.

In my first work I have already referred to the principle proposed by K. Angström and expressed the hope that it would after further improvements furnish the means of measuring the energy of solar radiation with an accuracy satisfactory to modern scientific demands.

My second work includes the theoretical investigations of the principle of Angström and the description of two instruments, of which one should serve for the absolute, the other for the relative, measure of solar radiation. As proposed by A. Crova, I have called the first instrument "pyrheliometer" and the second "actinometer."

The Angström principle requires the exposure of two bodies, as nearly homogenous as may be, alternately to the solar heat and in the shade. The difference, $\theta$, of the temperatures of these two bodies is observed; during the experiment, however, the body first heated will be cooling, while the other will become warmer. In consequence of this the quantity $\theta$ will sink to zero and become negative. By interchange of screens, the body before shaded will be exposed to the rays of the sun, and the other which had been heated will be brought into the shade. The temperature is then again noted. A change in the strength of the wind has but little influence on the magnitude of $\theta$. An increase in the velocity would accelerate the radiation and retard the insolation. This behavior I have specially investigated.

Angström has indicated a method of deducing from observations of the quantity $\theta$ the quantity $q$ expressed in calories, which is absorbed in one minute by a surface of one square centimeter when exposed perpendicularly to the rays of the sun. I shall here designate this method by the letter $A$. The method is as follows: The time $t$ is measured during which the quantity $\theta$ again reaches its absolute value, but, of course, with its sign reversed. Now, let $c$ be the capacity for heat of one of the bodies and $s$ the magnitude of the surface exposed to perpendicular radiation, then

$$q=\frac{2c\,\theta}{s\,t} \quad \ldots\ldots\ldots\ldots \quad (1)$$

I have, however, found that, starting with Angström's principle, another method can be followed which also will give the quantity $q$. This method I shall designate by $B$. It is as follows: Observations are made of three values $\theta_1$, $\theta_2$, and $\theta_3$ of the temperature difference $\theta$, corresponding to the times 0, $t$, and $2t$, then

$$q=\frac{2c}{s\,t}\cdot\frac{\theta^2_2-\theta_1\,\theta_3}{\theta_1-\theta_3} \quad \ldots\ldots\ldots\ldots \quad (2)$$

here $\theta_1$ and $\theta_2$ must have opposite signs so that all terms of (2) shall be positive. Formula (1) is much simpler than formula (2) and one may be inclined to think that method $A$ is preferable on that account. This advantage, however, will be diminished by a variety of circumstances. Above all, it is to be noted that both formulæ are only approximations and that a correction should be added to them. This correction for (1) is four times as large as that for (2); in method $A$ this can not be neglected, but in method $B$ it may nearly always be disregarded. The main point, however, is the construction of a portable actinometer for observations made according to method $B$.

The pyrheliometer constructed at the observatory of Pavlosk may be viewed as a modification of that of Angström. The bodies alternately insolated and shaded are two round copper plates of 30 mm. diameter and 5 mm. thickness. Their temperature difference, $\theta$, is measured by thermo-electrical means employing german silver and copper wires soldered to the plates. A special arrangement permits one at any time to measure the sensitiveness of the strength of the current due to changes of temperature. This sensitiveness is measured by the deflection of the magnet of the galvanometer for the value of $\theta=1°$.

I have investigated in detail all minor circumstances and sources of error which might possibly influence the observations, specially referring to the pyrheliometer, as well as in a general way with reference to methods $A$ and $B$. These theoretical investigations are contained in my last publication, No. 17. I desire to direct attention to a few of the considerations.

The influence of changes in the force of the wind or changes in

radiation during the observation, inequality of the bodies, unequal heating due to the secondary sources of heat, etc., are here included. I have investigated exhaustively the distribution of heat on the exposed plate and also the effect on the condition of the heat of the plates with reference to the influence of the wires soldered to them; also, the question of the retardation of the magnet moving under the influence of a continually variable strength of current and subject to a strong damping effect. I have also determined by a special method the constants of the differential equation of motion of the magnet with reference to the galvanometer employed. The motion proved to be almost a-periodic. It became evident that the magnet lagged considerably, so that its direction at any one moment did not properly represent that due to the strength of the current then passing through the galvanometer. With a velocity of 240 scale divisions per minute, the magnet constantly lagged behind 6 divisions. Fortunately it turned out that this large retardation had no influence on the results of observation by either method *A* or *B*.

*The actinometer.*—Observations with this instrument should be made by method *B*. It is illustrated in the accompanying figure (Plate XL), and it consists of two thermometers whose scales are close together in the direction of the solar rays; their lower ends are shown at *m*, the mercurial bulbs are shown above at *MM*. They have the form of spirals and are inclosed in flat copper vessels; their surfaces are gilded, excepting the upper faces, which are blackened. The space left free within the copper box is filled with copper bronze. By means of the thumbscrews *f* and *g* each of the two thermometers can separately be shifted up or down. The temperature difference present at any moment can be measured in the following manner: A square frame can be secured immovably at any desired place along the scales; to this frame is fastened, horizontally, a very thin blackened wire; this wire extends alongside the two scales. Through a large magnifying lens, *r*, this wire, as well as the two ends of the mercury column, are simultaneously visible. The proper position of the observer's eye is secured by a horizontal line marked on a small silvered plate placed between the thermometers; this line and the mercury surfaces must be in coincidence. It is now necessary to shift the two thermometers by means of the thumbscrews *f* and *g* in such a way that the ends of the two mercury columns remain continuously in the wire. For instance, supposing the left thermometer to be heated and the right one to be cooled, as is shown in the drawing (see the position of the screen *PP*), the left one must then be moved upwards and the right one downwards; to do this both screw heads *f* and *g* are turned in the same direction. Experience has shown that even an observer of little practice very soon learns to follow simultaneously the motion of the two mercurial columns and to keep their ends flush with the wire. A chronometer beating seconds with a loud beat, or a metronome which indicates every tenth beat by a

bell, may be used to record the time corresponding to the observation of the temperature difference $\theta$. While counting the beats the observer follows the motion of the mercury columns of the thermometers. At the proper moment the screws at $f$ and $g$ are turned and the temperatures of the two thermometers can be conveniently read off. These are determined by the position where the wire cuts the two scales, which are graduated to tenths of degrees. The hundredth part of a degree may be estimated. After the two temperatures have been recorded the two thermometers are shifted as much as may be needed; the motion of the two ends of the mercurial columns are again carefully followed and the time of a second observation is noted. The particulars of the process must be read in my descriptive paper. It is easy to get a coincidence at intervals of half a minute. Observing for two minutes we get five values of the temperature difference, the first two of which will be positive and the last two negative in sign; the third value should be as small as possible. We shall designate the first, third, and fifth by $\theta_1$, $\theta_2$, and $\theta_3$; they will give a relative measure of the radiation by formula (2), when $t=1$.

$$\text{If we put } q=K\,\Omega_1 \quad \dots\dots\dots\dots \quad (3)$$

$$\text{we have } \Omega_1=\frac{\theta_2^2-\theta_1\,\theta_3}{\theta_1-\theta_3} \quad \dots\dots\dots \quad (4)$$

The second, third, and fourth values will be designated by $\vartheta_1$, $\vartheta_2$, and $\vartheta_3$ ($\vartheta_2=\theta_2$). These give us a second relative value with $t=\frac{1}{2}$.

$$\text{If we put } q=K\Omega_2$$

$$\text{then } \Omega_2=2\,\frac{\vartheta_2^2-\vartheta_1\,\vartheta_3}{\vartheta_1-\vartheta_3} \quad \dots\dots\dots\dots \quad (5)$$

The observations should result in nearly equal values for $\Omega_1$ and $\Omega_2$, and here we have an excellent test for the reliability of every individual measure. I shall add a few examples. The first two columns give the direct readings of the two thermometers.

*Pavlosk, August 21, 1892—5 p. m.*

| ° | ° | ° | ° | | |
|---|---|---|---|---|---|
| 24.30 | 21.98 | $\theta_1=$ 2.32 | | | |
| 23.62 | 22.56 | | $\vartheta_1=$ 1.06 | | |
| 23.01 | 23.05 | $\theta_2=-0.04$ | $\vartheta_2=-0.04$ | $\Omega_1=1.014$ | $\Omega_2=1.018$ |
| 22.48 | 23.45 | | $\vartheta_3=-0.97$ | | |
| 22.00 | 23.80 | $\theta_3=-1.80$ | | | |

*Pavlosk, February 22, 1893—3 p. m.*

| ° | ° | ° | ° | | |
|---|---|---|---|---|---|
| −11.90 | − 9.89 | $\theta_1=$ 2.01 | | | |
| −11.22 | −10.16 | | $\vartheta_1=$ 1.06 | | |
| −10.66 | −10.50 | $\theta_2=$ 0.16 | $\vartheta_2=$ 0.16 | $\Omega_1=0.829$ | $\Omega_2=0.836$ |
| −10.35 | −11.00 | | $\vartheta_3=-0.65$ | | |
| −10.05 | −11.44 | $\theta_3=-1.39$ | | | |

*Pavlosk, February 27, 1893—3 p. m.*

| ° | ° | | ° | | ° | | |
|---|---|---|---|---|---|---|---|
| +1.35 | −0.65 | $\theta_1=$ | 2.00 | | | | |
| 0.95 | −0.05 | | | $\vartheta_1=$ | 1.00 | | |
| 0.63 | +0.55 | $\theta_2=$ | 0.08 | $\vartheta_2=$ | 0.08 | $\Omega_1=0.859$ | $\Omega_2=0.858$ |
| 0.31 | +1.05 | | | $\vartheta_3=$ | −0.74 | | |
| 0.15 | +1.65 | $\theta_3=$ | −1.50 | | | | |

The accord between the numbers for $\Omega_1$ and $\Omega_2$ proves the correctness of the theory and the usefulness of the method. A number of observations made simultaneously with a pyrheliometer and an actinometer demonstrated the complete proportional correspondence in the indications of the two instruments for radiations whose values range between the wide limits of 1 to 3.

The actinometric observations at Pawlowsk are not yet concluded. The question, "How are observations of solar radiation best made and collated?" I should answer as follows: The foundation must rest on the principle of Angström. The special method for absolute measures may be either that marked *A* or that marked *B* in connection with the pyrheliometer. For relative measures with a portable actinometer method *B* should be followed in the manner explained above.

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## 18.—THE STUDY OF THE UPPER ATMOSPHERE BY MEANS OF BALLOONS.

Dr. V. Kremser.

The conviction is becoming more and more general that an accurate knowledge of the physical conditions of the upper strata of the atmosphere is a fundamental condition for the progress and perfection of meteorology. The various mountain observatories have already contributed interesting and important data to that end (I need only refer to Sonnblick, Ben Nevis, and Pikes Peak as more recent instances), and the further utilization of the observations collected by them will doubtless furnish much additional information concerning the physics of the atmospheric ocean. But it is evident that these observations, influenced as they are by the position and character of the mountains, can not represent in a natural manner the conditions of the free atmosphere, and can, therefore, be used in a qualified sense only.

We are also indebted to cloud observations for valuable information regarding atmospheric conditions, especially as to atmospheric circulation. But these furnish only occasional glimpses in a fixed direction, and by no means sufficiently dispel the obscurity enveloping the physical character of the air strata considered collectively, and the influences they exert upon each other.

The principal method for determining all properties of the atmosphere at different heights is by means of the balloon. All those

meteorological elements which we observe in order to characterize the weather on the surface of the earth may be determined by means of the balloon up to heights where the changes in the existing conditions are inappreciably small.

Scientific use of the balloon in this direction was made in the very first year of its invention. The first savant to risk an ascension for the purpose of taking meteorological observations was an American, John Jeffries, of Boston, Mass., who ascended with Blanchard, on November 30, 1784, from London, and who observed the temperature, moisture, electricity, and chemical composition of the air up to an elevation of about 2,800 meters. He found that the temperature fell about 0.5° C. per 100 meters, and that the humidity decreased toward the upper regions.

This first experiment fell into oblivion, and the honor of having been the first scientific balloonist was, until the present time, awarded to the Belgian physicist Robertson. The latter ascended from Hamburg on July 18, 1803, and is reported to have reached a height of 7,400 meters on that occasion, during which the temperature fell from +20° to −7° C. The results of this ascension, as well as those of a second one, also from Hamburg, and finally of a third one, from St. Petersburg, which Robertson and the naturalist Sacharoff made at the instance of the Academy of that place (ascensions in which electrical and magnetic conditions were made special features of observation), excited great interest everywhere, especially at the Academy of Paris. This institution prepared a complete programme for scientific ballooning, and selected Biot and Guy-Lussac to execute the same at the expense of the Academy. On the 24th of August, 1804, these two ascended to a height of 4,000 meters, and endeavored to acquit themselves of their task in a creditable manner; but their observations did not lead to any absolutely satisfactory results, either as regards the action of the magnetic needle or as to atmospheric electricity, and also not as regards the decrease of temperature with elevation. On September 16, 1804, Guy-Lussac went up alone, for the purpose of completing and verifying the observations made during the first voyage; and this time he reached a height of 7,000 meters. The magnetic force showed no change with elevation; the temperature fell from +28° to −10° C.; but most important of all, the samples of air brought down showed that the chemical composition of the air is the same everywhere, up to an elevation of 7,000 meters.

Guy-Lussac's wish for an opportunity to make additional ascensions was not realized; but his example produced occasional imitators, at least within the next following years. Jungius ascended from Berlin in 1805, and Brioschi from Padua in 1806; but no results of scientific value were obtained in either case.

A long pause now ensued in the utilization of the balloon for atmospheric investigations, and it was not until the beginning of the second

half of the present century that this was followed by a season of renewed activity.

In 1850, on June 29, and again on July 27, Barrall and Bixio made balloon ascensions from Paris and reached a height of 5,900 and 7,000 meters, respectively. These voyages did not turn out very fortunate ones, and the observed data—at least those relating to temperature—did not appear to be sufficiently reliable, especially as regards a reported temperature of —39° C. at an elevation of 7,000 meters, which was justly regarded with suspicion. On the other hand, they established beyond a doubt the existence of clouds more than 3,000 meters in thickness, the presence of ice spiculæ at greater elevations, and the connection of the latter with the optical phenomena of the atmosphere, and finally, that the light reflected from clouds was not polarized.

Next in order to attempt the study of the upper atmosphere come the English scientists, who carried out their programme in a systematic manner. At the outset four ascensions were arranged for at the instance of the committee of the Kew observatory in 1852, in which the observations were made by Welsh. These took place on August 17, August 26, October 21, and November 10, 1852. The greatest attained height was 7,000 meters, with a temperature of —24° C. The decrease of temperature was found to be by no means uniform; it was most rapid in the lower strata (0.7° per 100 meters), only a little less rapid in the uppermost strata, while in a certain middle stratum it fell to 0.2° per 100 meters. The mean decrease per 100 meters was 0.6° during the first ascension, 0.5° during the second, 0.43° during the third, and 0.46° during the fourth. The variation of these values with the season is at once apparent. They are greater in the summer (August) than in the fall (October and November). The humidity did not decrease as much with the elevation as during former ascensions, but came very near saturation; the light of the clouds was again shown to be nonpolarized; the air everywhere had the same composition.

Two circumstances render the results of Welsh's voyages significant, viz, the establishment, for the first time, of the fact that the decrease of temperature with elevation is influenced by the seasons, and (what has not before been referred to in this paper) his method of measuring the temperature in a balloon. Rightly considering that in consequence of the great solar radiation and the calm prevailing in the balloon, thermometers mounted in the ordinary way would hardly be able to indicate the true temperature of the air, Welsh, for the first time, made use of aspiration by putting the thermometers into narrow polished tubes, through which he caused the air to circulate by means of bellows, an innovation of the utmost importance to balloon observations, but which was not fully appreciated until the present time.

For the most valuable and complete observations hitherto collected from the free atmosphere we are indebted to Glaisher, whom the British

Association for the Advancement of Science enabled to make 28 balloon ascensions during the years from 1862 to 1866, in company with the skilled aëronaut Coxwell, and to supplement the results of those voyages by means of numerous ascensions in captive balloons during the year 1869. As the data then obtained are still considered to furnish in many respects the best basis for our knowledge of the meteorological conditions prevailing in the upper atmosphere, it is proper to refer to them more in detail.

The programme was, on the whole, the same as that for the former scientific voyages, only still more explicit. The supply of instruments was abundant; they were accurately tested in advance, the thermometers also with aspiration, and the manner of their erection and exposure was determined upon once for all. In order to obtain a large number of observations, with special reference to the usually short duration of the voyages on account of the insular position of England, they were made at very short intervals. The aërial voyages were made for the most part during the afternoon hours of the summer months, some also in the spring and fall, and a single one in winter. Coxwell could not be induced to make a night voyage. Three times a height of more than 7,000 meters was reached; once, on September 5, 1862, a height of 8,800 meters was reached with certainty, and according to certain indirect calculations, 11,000 meters.

Glaisher compiled and discussed his observations himself. Some of the principal results are given below:

The fall of temperature per 100 meters averages 0.9° C. in summer, at a mean height of 500 meters; at 1,500 meters only 0.6° C., and grows smaller until at a height of 8,000 meters it hardly averages 0.2° C. In the autumn and spring the values are somewhat smaller, viz, 0.7° C. at 500 meters, 0.5° C. at 1,500 meters, and 0.2° C. at 6,000 meters. The rate of fall, therefore, diminishes with increasing elevation, and this holds good in clear as well as in cloudy weather. It is more rapid in clear than in cloudy weather; up to 300 meters the fall is 1.0° C. per 100 meters in clear weather, and 0.8° C. in cloudy weather; at 7,000 meters it is only 0.18° C. in the former, and only 0.15° C. in the latter case. The observations made in a captive balloon, which became necessary for the study of the lowermost air strata, because the free balloon rose too quickly above them, disclosed, above all, a daily period in the course of the vertical decrease of temperature in the open air, which for the hours from 10 a. m. to 7 p. m. admitted of a very reliable numerical representation.

The mean relative humidity increases in clear as well as in cloudy weather up to 1,000 meters; then it decreases up to 3,000 or 4,000 meters; beyond that height it appears to increase again, and finally to decrease at greater elevations. But the observations above 4,000 meters were not numerous enough to produce sufficiently reliable results. Even at great elevations there is an irregular alternation of

dry and wet strata, but in a manner to show an unmistakable tendency to great dryness.

Similar general and at the same time numerical laws regarding the direction and velocity of the wind could not so well be deduced from Glaisher's voyages, because they were mostly too short. That the velocity is greater in the upper regions than on the surface of the earth, and that there exists almost always different wind directions at different elevations, must be considered as the sole general result. The spectroscopic and electrical observations disclosed nothing new or sufficiently reliable.

Highly meritorious as Glaisher's ascensions are, the results should by no means be considered as conclusive. Aside from the fact that a careful review of his observations will disclose obvious errors in the readings, it must be remembered that the vertical velocity of the balloon was frequently so great that the thermometers could hardly keep pace with the temperature changes; that there were too many observations within short periods of time to attain the desired simultaneousness; and that the exposure of the thermometers inside of the car, over a small table, and the manner of aspiration were not calculated to obviate the effects of radiation. With all due acknowledgment of Glaisher's merits, it is nevertheless very desirable to subject his observations to further scrutiny, and to repeat them with the exclusion of the several sources of error above referred to.

The example set by Glaisher found no followers in England, but it awakened a renewed and lively interest in the matter of scientific ballooning in France, the native land of the balloon. Of those following in Glaisher's footsteps special mention must be made of Flammarion, De Fonvielle, and Tissandier, who made numerous ascensions for scientific purposes from 1867 until almost the present time, the results of which have been made public.

Although no new or more particular information was obtained concerning the distribution of temperature and moisture in the upper atmosphere, and although, in consequence of the manner in which the instruments were exposed and read off, the results are by no means more reliable than those of either Welsh or Glaisher, yet these voyages produced a rich store of interesting observations, with numerous details. Mirages, Brocken spectres, mock suns, and other optical phenomena; the existence of ice crystals; the shape and dimensions of clouds, their height and daily period; change in the direction and velocity of the wind with elevation, especially in the presence of lower clouds; height of the border stratum between land and sea breezes, etc.; all these were objects of successful investigation, for which meteorology stands indebted to French scientists, the more so because they did not allow themselves to become discouraged by the fate of Sivel and Crocé Spinelli, who were killed in an ascension made for scientific purposes on April 15, 1875.

During and since the eighties a zealous interest for scientific ballooning has manifested itself almost simultaneously in many countries. In the United States a series of balloon ascensions was arranged for by the Signal Office (now Weather Bureau), at the suggestion of Cleveland Abbe, which took place in 1885, and which were noteworthy in fixing the relation of the meteorological elements in the upper regions, especially as regards winds, to the weather conditions below. Hazen made a number of voyages in 1886 and 1887; his results have been discussed by himself. In Italy several balloon ascensions were made in 1884 and 1885 from Turin and Rome, and the data put to scientific use by Denza. In Russia not only was the balloon used for purposes of observation by individual scientists, like Rykatschef and Mendelejeff, but useful material for the investigation of atmospheric conditions was also collected in the voyages made from St. Petersburg under the auspices of the Imperial Russian Technical Society and the officers detailed for instruction at the balloon park. From forty of these voyages Pomortzeff has drawn interesting, if not always sound, conclusions concerning the dependence of the wind, temperature, and moisture of the air upon elevation, and upon the distribution of atmospheric pressure on the surface of the earth. In Austria, also, balloon voyages have been put to scientific uses, in connection with which the names of Hoernes, Margules, and Tuma are mentioned as specially active participators.

In Germany it is especially the German Society for the Promotion of Aërial Navigation, at Berlin, and its sister society at Munich, that have made their special aim the widest possible utilization of the balloon for meteorological purposes. Thanks to the energy and public spirit of several private gentlemen and of some officers of the military corps of aëronauts, an enterprise has been developed here by which the investigation of the atmospheric ocean, if it is not quite carried to a successful conclusion, will at least be materially advanced in a systematic manner.

After a series of strictly scientific ascensions by individual members of the above-mentioned society, the Academy of Sciences at Berlin, on the recommendation of Von Bezold, came to the support of the undertaking, and eventually the Emperor of Germany assigned a considerable sum of money to the prosecution of aërial voyages on the broadest basis.

The aims and methods followed in Germany may be objectively considered as best corresponding to the present status and modern requirements of meteorology. The leading features of the system will be briefly described, as follows:

Assmann's investigations for ascertaining the true temperature and moisture of the air have made it obvious that thermometric readings made in a balloon are unfit for scientific use, unless very special precautionary measures have been applied, because solar radiation at great elevations, in connection with the absence of wind in the balloon,

influences the readings in a high degree. Neither the use of screens ("Beschirmungen") nor of sling thermometers can prevent these errors, as has been demonstrated by practical experiments. Even aspiration thermometers may still have serious errors, if the aspiration is not sufficient, or does not work properly, or if the local environs have not been carefully selected. For these reasons all former balloon observations appear uncertain and questionable; for even those of Welsh and Glaisher can not be considered as corresponding to the actual state of the temperature and moisture of the free air, because the thermometers, though aspirated, were exposed inside of the car, above a table, where the heat from the observer's body and from the heated table affected the readings. It is therefore a prime necessity to revise and correct the former data regarding temperature and moisture, by proper exposure of good aspiration thermometers or psychrometers, placed outside of the car and at a sufficient distance from the observer.

But the barometer, also, is unmistakably influenced by sunshine and shade. Even the so-called compensated aneroids continue to show the effects of insolation at the higher elevations, to which must be added the errors resulting from uniform elasticity. But the latter can and therefore should be ascertained by comparison with a mercurial barometer, which should at least be so far protected from radiation that it has the same temperature along its entire length, including the attached thermometer, even if that temperature be higher than that of the air. Further, in view of the varying vertical velocity of the balloon, which, as a matter of course, affects the height of the mercury, the mercurial barometer should be used as a check on the aneroids at such moments only when it may be supposed that there is no variation in the vertical velocity, preferably, therefore, when the balloon has attained, and for some time maintains, a position of equilibrium. It is at great elevations, especially, that these facts and instructions should receive the most painstaking attention, because then small changes in pressure correspond to considerable changes in height.

In order to increase the number of observations without lessening their value, preference should be given to self-registering aspiration instruments, which need only be occasionally standardized by direct observations.

To ascertain the direction and velocity of the wind at different heights, it is necessary to plot frequently the balloon's position on accurate charts, with a statement of the time; or, under certain circumstances, to determine it by trigonometric or micrometric observations.

As in the present status of meteorology it is not only a question of determining reliable mean values, but still more of investigating typical or particular weather conditions, especially atmospheric conditions, and of tracing them back to their physical causes, therefore an accurate knowledge of the meteorological conditions on the surface of the earth, and of the changes in the same during a balloon voyage, are indispensable if

the observations are intended to be utilized for that purpose. This requires the coöperation of meteorological observers and the closest possible network of stations in the localities over which the voyage is made. Where mountain observatories or elevated stations are available, their observations will be of additional value in deducing the relation of mountain observations to those made in the free atmosphere.

Further, it appears very desirable to have simultaneous observations from a number of different elevations, and these may be obtained by using balloons of different carrying capacity, which will float at elevations corresponding to their power.

Finally, it would be of the utmost value if balloon voyages were made not at one point only but simultaneously from several places in a large district, in order to obtain a knowledge of the physical differences existing at the same level and over the widest possible extent, and make them the basis of our investigations.

In addition to determining the ordinary meteorological elements during each voyage, special ascents are necessary for observing the electrical, optical, and magnetic conditions of the upper regions in an unobjectionable manner.

Such, then, are the ideas and aims of the Berlin Aëronautical Society, which, assisted by the Munich Society for Aërial Navigation, has already commenced to put them into practical execution. The outfit of instruments, their exposure and usage, are in harmony with the considerations outlined in the foregoing. Numerous stations in Germany make observations at short intervals, when a balloon voyage is under way; and the employment of a number of large balloons makes it possible to take simultaneous observations at different heights. The entire plan was first put into practical operation in 1888, when two members of the Society, Sigsfeld and Kremser, made the first voyage in a free balloon. Soon afterwards a captive balloon was also built, which was equipped with self-registering aspiration instruments for pressure, temperature, and moisture of the air, and allowed to rise to a height of 800 meters. Under the direction of the energetic president of the Society, Assmann, the enterprise was rapidly developed. Numerous voyages were made in 1891, participated in notably by Assmann and Berson, and in connection with which the captive balloon was put into actual use. Since 1889 free-balloon ascensions have also been made from Munich. Finally, through the munificence of the German Emperor, the Society has been put in a condition where it can with a large balloon penetrate to the highest regions that can be reached by man, and at the same time explore the middle regions with a balloon of medium size and the lower strata with a captive balloon. The simultaneous coöperation of the Munich Society has been assured to that end. Thus we see in full activity at the present moment an undertaking from which we are justified in expecting valuable results.

In concluding this description of the present status of atmospheric study by means of the balloon, it is also necessary to refer to several

special experiments which promise to prove of considerable value in supplementing the German plan now about to be carried into practice.

To this class of investigation belongs the systematic study of the movements of superimposed air strata. Balloon observations have shown that the direction and velocity of masses of air are very different at different heights. Large, manned balloons are not quite suitable for the accurate and frequent determination of these differences, for the reason that their expensiveness, their relatively small vertical ascent as compared with their horizontal motion, and, in a certain sense, the usual manner of locating them by plotting their course upon charts, render their use objectionable. On the other hand, the direction and velocity of air currents immediately succeeding each other in a vertical direction can be easily, quickly, and accurately ascertained by means of trigonometric or micrometric observations of small paper balloons, the so-called pilots, of great buoyancy. Indeed, with certain methods of calculation even the vertical components of the air currents may be determined in this manner. Kremser has inaugurated the systematic consummation of this idea in Berlin, and has also endeavored to have it carried into effect at other points.

Unmanned balloons have also furnished the means for a still more important experiment undertaken by Hermité, of Paris. He has succeeded in constructing self-registering apparatus for the pressure and temperature of the air, of such lightness that balloons of small volume are able to carry them up to the highest strata of the atmosphere, never attainable by man. By this means the temperature conditions at elevations of 20 kilometers and more will probably be known; and by observing the balloon from below, in the manner already pointed out, the wind phenomena may also be determined. On March 21, 1893, such a balloon reached a height of 16,000 meters, where the temperature registered $-21°$ C., while at 12,500 meters it registered $-51°$ C. This demonstrates the feasibility of the plan, but at the same time renders it certain that the insolation of the instruments produces effects entirely at variance with the actual conditions of the atmosphere. Here, also, trustworthy data can only be obtained by protecting the instruments from the effects of insolation by means of continuous aspiration.

Little has been said in this paper of the frequent attempts which have been made to observe the electricity of the air, because no positive results have been reached from these very difficult observations. But the efforts which are being made, contemporaneously, at many places justify the conclusion that in this direction, too, we will soon be in possession of reliable data; and this view is confirmed by the satisfactory experiments of Tuma, during a balloon voyage from Vienna September 15, 1892, which indicated that the potential was positive at all elevations, and that it increased with the height.

In view of the problems touched upon in this paper, and probably of some others, it must be admitted that the balloon will remain for a long time a valuable means for investigating atmospheric conditions.

## 19.—OBSERVATIONS OF ATMOSPHERIC DUST.

JOHN AITKEN.

"And, Master, if it please,
I shall recite how many sun-motes lie
From end to end within a yôjana."
—[The Light of Asia, Book the First.

Before beginning this communication, I must apologize for the very limited view I shall be able to give of what is a wide and most interesting field of inquiry. When I received the invitation of the chairman of the committee of the World's Congress Auxiliary on a Meteorological Congress, I was just setting out for the Continent of Europe. This communication will, therefore, have to be written at intervals while traveling, and at a distance from all books of reference. As my knowledge of what has been done by others is not sufficient to enable me to write without reference to their papers, my communication must, therefore, be confined to the narrow field in which my own investigations have been made. This communication can not, therefore, avoid appearing of too personal a character; but in judging it I trust the conditions under which it has to be written will be considered, at least, as a partial excuse for its many imperfections.

In treating of the particular department of atmospheric dust to which my work has been devoted, perhaps the best plan will be to treat it in what might be called the historical manner. By this plan the successive developments which the subject has undergone will be most easily followed, as by this manner of treatment anyone approaching the subject for the first time will the more easily and firmly fix his footsteps, if he travel along the same road as that taken in the original investigation.

During the year 1875, I had been studying the phenomena connected with the change of matter from one condition to another—from the liquid to the solid state, and vice versa, and also from the liquid to the gaseous condition, and was impressed with the importance in all these cases of what I have called a free surface at which these changes may take place, because what are known as the freezing and boiling points are the temperatures at which these changes take place at a free surface. At present we know nothing as regards the temperature at which the changes will take place if no free surface be present. For instance, if we cool water with ice crystals in it, it freezes at 32° F.; but if we remove all the ice the water may be cooled to a temperature far below the freezing point before liquid particles will combine together to form ice. The freezing point is that temperature at which liquid particles combine with solid ones. So, again, water boils when its temperature rises to 212° if a free surface be present at which the change from liquid to vapor may take place; but if the water be in contact

with the vessel in which it is heated, and its upper surface be closed, say, with a layer of oil, so that there be no free surface in the water, then its temperature must be raised far above 212° before the change can take place. At present we do not know how high a temperature is necessary to force asunder the molecules of water when surrounded on all sides by other molecules of water. The temperature to which water with no free surface may be raised without change of condition seems to depend on the more or less perfect adhesion of the water to the surfaces with which it comes in contact, as the free surfaces under these conditions are formed at some weak point of contact, and not in the interior of the mass; and when a free surface is formed under these conditions, the water boils with explosive violence, owing to its high temperature.

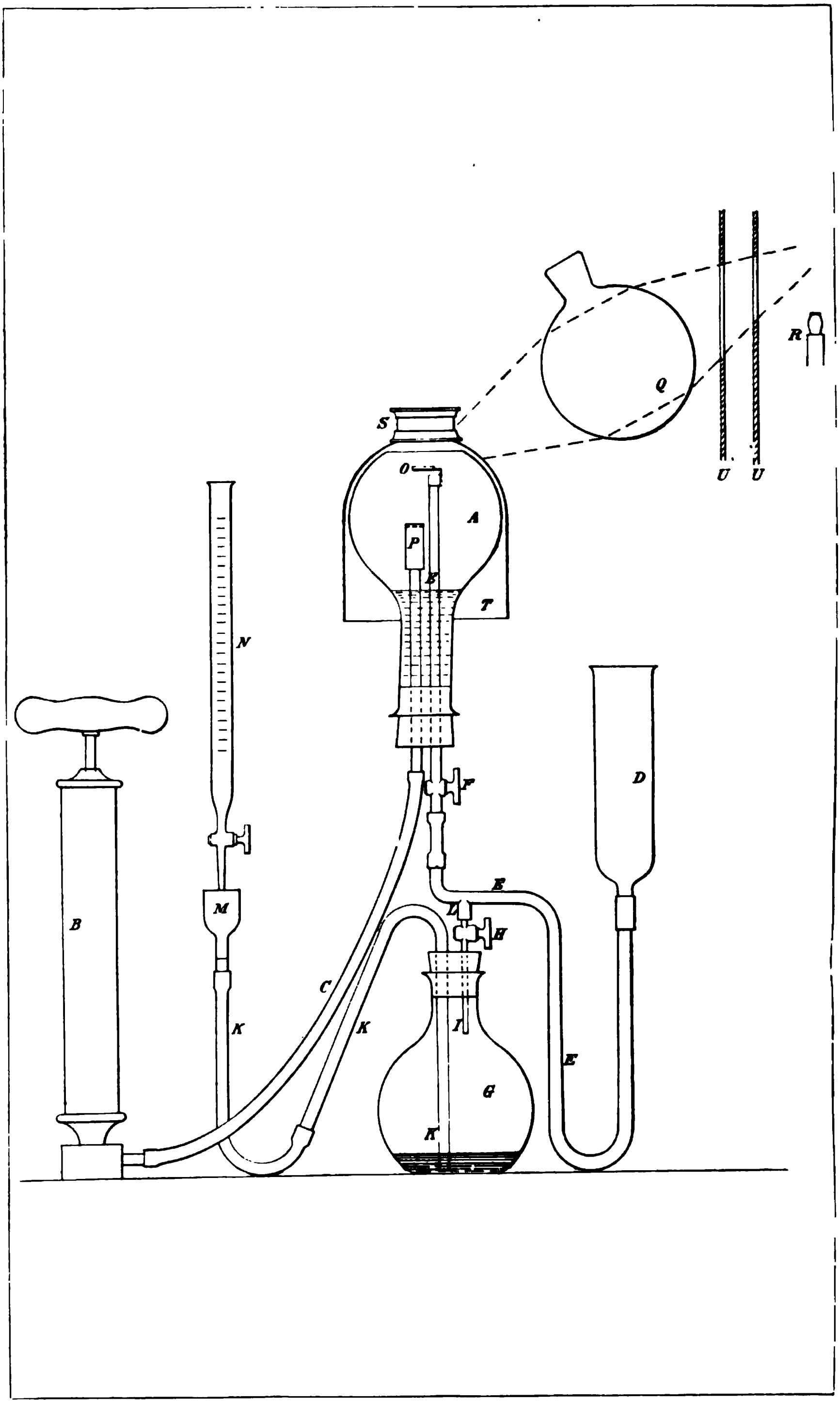
Continuing this line of thought, it appeared very probable that when the reverse process took place, and the steam condensed to water, that a free surface would be necessary for the change to take place at, if that change was to take place whenever the temperature fell below what is called the boiling point for the pressure. If no free surface be present in the steam, it seemed probable, reasoning from analogy, that the vapor would not condense till it was cooled far below the boiling or condensing point, just as water may be cooled far below its freezing point without becoming solid. Of course, the sides of a vessel containing a liquid, or a vapor, act more or less as a free surface at which the change may take place. In freezing the sides do not form a perfectly free surface; but, so far as we know, all surfaces act as perfectly free surfaces for the condensation of vapor. But while the vapor in contact with the sides of the vessel condenses as the temperature corresponding to the pressure, what happens in the interior of the mass of the vapor, where there are no free surfaces? If the vapor be cooled, say, by expansion, to a temperature below its condensing temperature, will it condense? Or will the water vapor act as liquid water does, and refuse to change its state except at a free surface?

To answer the above question experiments were made with steam, but without elaborate and expensive apparatus I found it difficult to get a satisfactory answer. After a few preliminary trials with imperfect apparatus, it became apparent that the experiments might be made with simple apparatus, and working at a lower temperature, if the steam were mixed with air. But on mixing steam with the air in the receiver in which the experiments were to be made, the ordinary well-known cloudy condensation took place. The receiver became full of a cloud of condensed steam. The formation of that cloud jarred on the somewhat nebulous condition of my ideas at the time. Water does not suddenly change into ice at hundreds of centers all through its mass. Nor does it change to steam except at a few centers at the outside limits of the mass. Why, then, did the steam change to water at a hundred centers all through the mass? Could vapor molecules

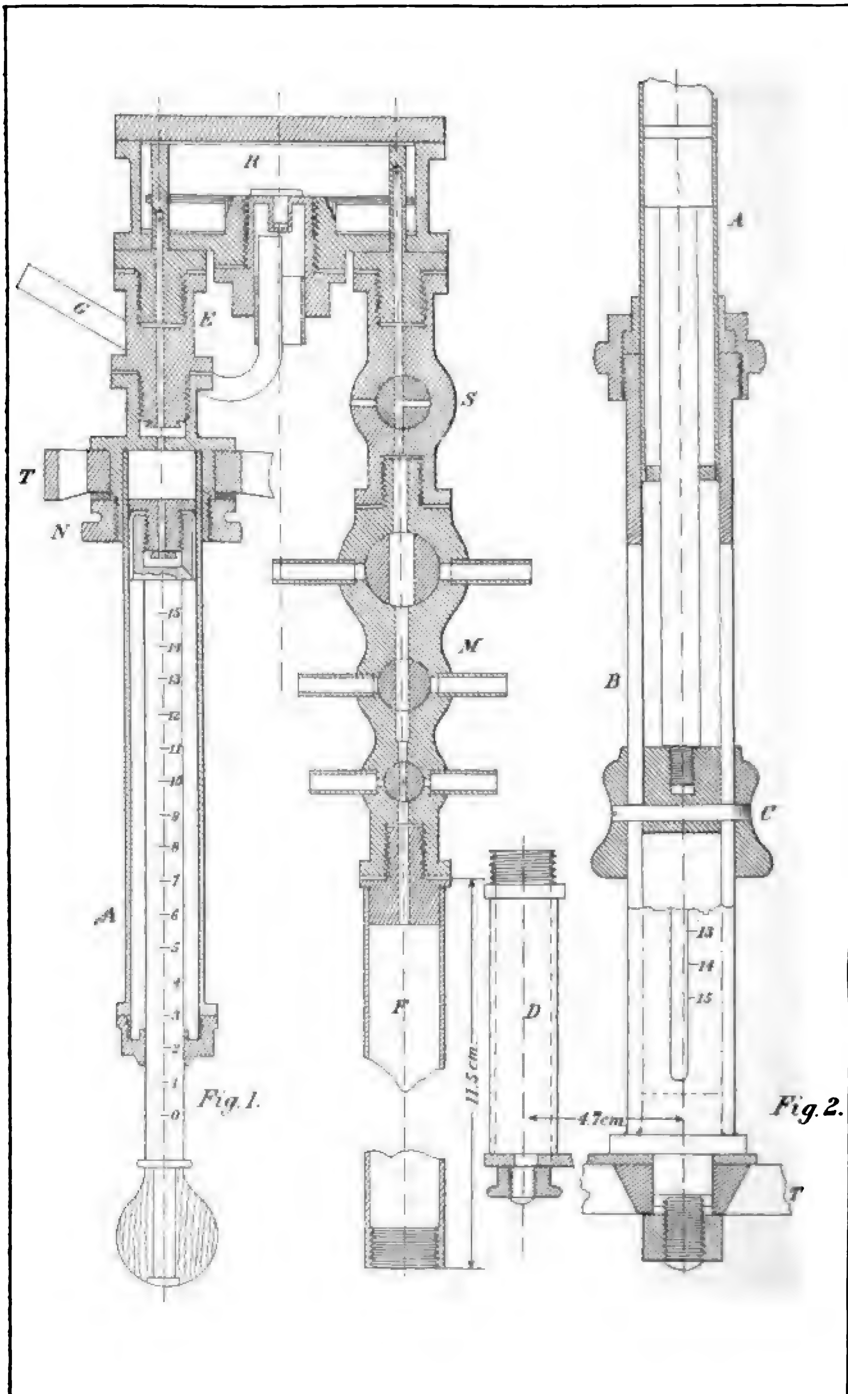
combine with other vapor molecules to form water without a free surface, while the reverse process can only take place at such a surface? On considering the conditions of the experiment, the question naturally suggested itself: Might not the dust in the air play some part in the condensation of the steam? Might not the dust particles be free surfaces on which the steam condensed? To answer this question the receiver was filled with dustless air, the air being freed from its dust by passing it through a filter of cotton wool. Now, on admitting steam to the receiver, no condensation took place, the receiver remained free from clouding, and if the sputtering of the entering steam and a fine rain had not been observed, it would have been hard to realize that the steam was entering and mixing with the air. This experiment at once demonstrated that vapor molecules do not combine directly with vapor molecules to form water, but that a free surface is necessary at which the vapor may change to liquid.

The above experiment was then modified in the following way: The receiver was connected by india-rubber tubes with an air pump and with a cotton-wool filter. A little water was put into the receiver to saturate the air with vapor. If the connection between the receiver and the filter be cut off, and a stroke of the air pump made, the air in the receiver is expanded and cooled; the result is that condensation takes place, the inside of the receiver becoming filled with a dense cloud. If we now admit air through the filter to the receiver, so as to restore it to its original pressure, and after it has been saturated with vapor, we again make another stroke of the pump, we shall get a second cloudy condensation in the receiver; but the second one will not be so dense as the first. If we again admit filtered air and again expand, another cloudy condensation will appear, but again it will be thinner than the previous one. If this process be repeated a number of times the clouding becomes less and less dense, the dusty centers of condensation become fewer and fewer, and the water particles will at the same time be seen to be growing larger and larger, till at last they can be seen falling like fine rain. After this stage is arrived at all condensation ceases, and the air remains unclouded on expansion, owing to there now being no dust particles in the air in the receiver. If we admit a little unfiltered air, or if the slightest leak break out in the apparatus, condensation at once begins again on expanding the air.

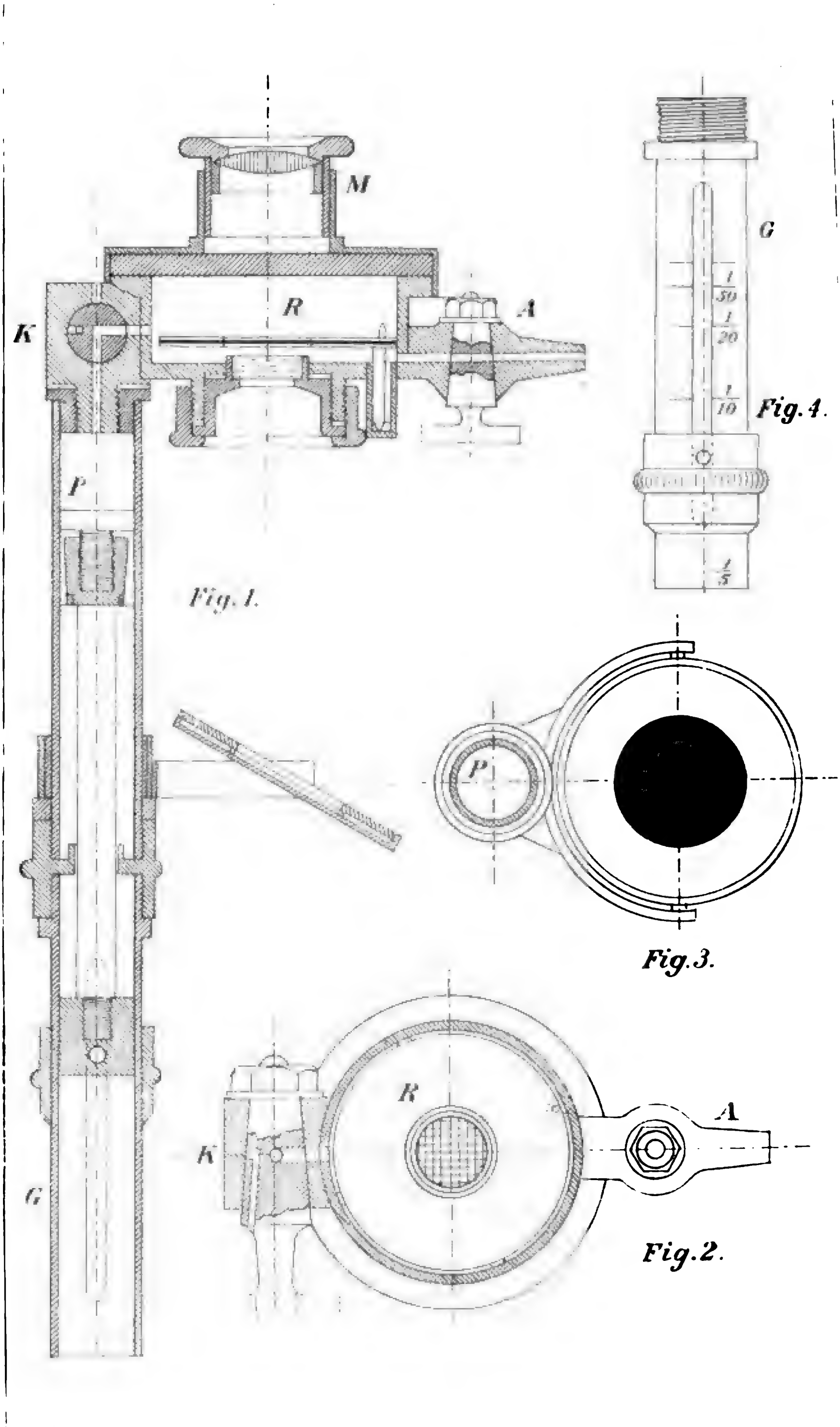
These experiments seemed to demonstrate that the dust in our atmosphere played a most important part in the economy of nature. If the above conclusion be true, it at once becomes evident that no cloud could form in our atmosphere without dust, and that every particle in a cloud before it became visible was represented by an invisible dust particle. The vast importance of this conclusion made it necessary that all points connected with it be more fully tested. Experiments were accordingly made to see if condensation really never took place without a free surface for the change to take place at. The result of




THE ORIGINAL DUST COUNTER. (AITKEN.)




THE FIRST PORTABLE DUST COUNTER. (AITKEN.)




THE POCKET DUST COUNTER. (AITKEN.)

these experiments is that it is possible for the vapor molecules to combine to form water without a free surface, if the strain be sufficiently great. If, for instance, we expand saturated air very rapidly, and accompany the expansion by a shock, condensation may take place in dustless air. The conditions necessary to produce condensation without the presence of dust are, however, so severe that so far as we are aware they never occur in nature.

At this stage of the investigation I ventured to predict[1] that—

If there were no dust in the air there would be no fogs, no clouds, no mists, and probably no rain; that dustless air, when it got into the condition in which rain falls—that is, burdened with supersaturated vapor—would convert everything on the surface of the earth into a condenser on which it would deposit itself. Every blade of grass and every branch of tree would drip with moisture deposited by the passing air. Our dresses would become wet and dripping, and umbrellas useless, etc.

To show how far this has been fulfilled, I shall now quote from Rankin's paper on Dust Particles at Ben Nevis Observatory, in the Journal of the Scottish Meteorological Society, Vol. IX, Third Series, No. VIII:

It is sometimes observed, and this, too, when the number of dust particles measured is extremely small, or even nothing, that the air is surcharged with vapor, if such a condition be possible, and that then, for want of dust particles to form on and so fall in drops, it simply condenses on all exposed objects direct from the air. This is the most wetting condition of the air; a few minutes in such air is sufficient to soak the observer, unless properly protected. Every post and rope seems running with water. While looking out one does not get the idea that it is nearly so wet.

Perhaps it may be asked, What reason is there for supposing that dust forms the nuclei for the condensation of the vapor? It is true, experiment shows, that no cloudy condensation forms in air that has passed through a filter of cotton wool; but may not the filtering check the condensation in some other way? It may be as well, therefore, that in addition to the theoretical considerations we briefly give some experimental reasons for supposing that particles of dust form the nuclei of condensation. First, then, because no cloudy condensation forms in air that has been passed through a cotton-wool filter, and we know the filter keeps back dust, but we know of no change effected on the air by the cotton wool. Second, air passed through a thermic filter, that is, through a narrow passage, one side of which is hot and the other cold, is freed from its visible dust, and it is at the same time made incapable of producing cloudy condensation. Third, an electric discharge into air deposits the visible dust, and it also makes the air incapable of cloudy condensation. Fourth, moist air alternately expanded and condensed, and the cloudy condensation formed at each expansion allowed to fall, at last loses all power of condensing and remains clear on expansion after the repeated showers have condensed on the dust particles and carried them all down. Supposing none of these reasons to be satisfactory, yet it will be admitted

[1] Trans. Roy. Soc., Edinburgh, Vol. XXX, Part I.

that the following is conclusive: Do nothing whatever to the air, simply leave it alone; close the receiver and cut off all communication with the outer air. After a time the air in the receiver becomes incapable of giving cloudy condensation. It will take time for all the dust to settle, a day if the flask be small, many days may be necessary if it is large. Now, we do not know of any change which can take place in the air under these conditions, save the settling of solid or liquid matter. All these five considerations point to the conclusion that the vapor condenses on the dust particles in the atmosphere. What may be the sources of all these particles it is difficult to tell. No doubt some of the dust is meteoric, the product of the combustion of the myriad of meteors showered into our atmosphere every day. But probably the greater amount of the dust is due to fires. In some cases these particles are so excessively small as to appear almost molecular, yet their condition is solid, or liquid, as they do not diffuse, but settle out of the air.

Having established the important fact that cloudy condensation in our atmosphere can only take place in the presence of dust; that every cloud particle was previously represented in the atmosphere by a dust particle on which the vapor forming the cloud particle condensed, it seemed therefore probable that dust might play an important part in other meteorological phenomena, and if we could devise some way of estimating or counting the number of particles of dust in the atmosphere, that a new field of meteorological inquiry might be opened up, as it seemed probable that these small particles might play some unknown part in the economy of nature. Attempts have been made by others to collect dust in various ways, but none of them are suitable for giving the number of particles in the air tested, the objects of previous investigators being to get the weight and the composition of the dust falling in a given time. The experiments on cloudy condensation, however, suggested a method of counting them. Though many of the particles are too small to be seen with the highest powers of the microscope, yet it appeared to me that by making these extremely small particles, as well as the larger ones, centers of condensation—that is, making them the nuclei of small raindrops -it might be easy to count the raindrops so formed and in this manner obtain the number of dust particles.

When ordinary air is saturated and expanded the cloud is so dense that it seems as hopeless to attempt to count the different centers of condensation as to count the motes in a sunbeam. The particles are extremely numerous and light; they float in the air and quickly pass from our field of view. But when we increase the amount of dustless air—that is, reduce the number of dust particles present—then the centers of condensation becoming fewer, each cloud particle gets more vapor deposited on it, and being larger falls rapidly, and now in that condition it becomes evident we have some hope of being able to count

them, by allowing them to fall on a micrometer and counting them by means of a lens or microscope. Further, as we can always make the number of dust particles—that is, centers of condensation—in a given volume of air as small as we wish, by mixing a small amount of dusty air with a large amount of dustless air, we can thus always obtain the conditions necessary for counting, and by simply allowing for the proportion of the dustless to the dusty air, we can make the correct allowance for the dilution when calculating the number of particles.

Though the possibility of counting the dust particles thus became evident, yet much work was necessary before it could be accomplished. The first difficulty was to find some surface on which the drops could be easily seen and counted. For many reasons glass seemed the most suitable substance, but at first its use had to be abandoned on account of the difficulty of seeing the drops after they fell on it. Silver was the substance next experimented with, and it gave most satisfactory results, the drops being easily seen and counted on it. The silver was simply highly polished, in a particular way, and ruled into small squares of one millimeter. This silver micrometer was illuminated by means of a gas flame, the light being concentrated on it by means of a water lens, or ordinary daylight could be used. The drops were counted by means of an ordinary compound lens, no great magnifying power being necessary. Owing to the manner of polishing and of illuminating, the field appeared black, and on it the little drops shown out brightly, and were easily counted.

The apparatus by means of which the dust in the atmosphere was first counted is shown in Pl. XLI. As will be seen, it is constructed of pieces of apparatus which can be easily obtained ready-made. A is the receiver, an ordinary flat-bottomed flask, in which the air to be tested is cooled by expansion, and the number of drops is counted. The receiver A is connected with the air pump B by means of the india-rubber tube C and with the filter D through the tube E. To saturate the air, some water is always kept in A. The drops are counted on the micrometer, O, which is made of a plate of silver 1 cm. square, highly polished, and ruled with lines at right angles to each other and 1 millimeter apart. It is illuminated by the gas flame R, the light being concentrated by means of the water lens Q. When the micrometer is in its place there is exactly 1 cm. between its surface and the top of the receiver. The drops are counted by means of the lens S. To the pipe E is attached a branch, L, by means of which the air to be tested is introduced into the receiver A. India-rubber tubes and stoppers are used for fitting the different pieces together, and care must be taken to insure that the joints are perfectly air-tight. After the apparatus is fitted up, as shown, the stopcock F is opened and H is closed, after which the air pump is worked till all the impure air is removed from the receiver and its place taken with dustless air from the filter. After a short time the stopcock F is closed and a stroke of

the pump made. This expands the air in A, and if there are any dust particles in it a shower of rain will be seen falling on the micrometer, on looking through the lens S. If any drops fall, more filtered air must be admitted, expansion made, and if still some drops fall, the process must be repeated till the drops cease falling, which will take place when the air is perfectly free from dust.

The apparatus is now in a condition for making a test. To do this the flask G is disconnected from L and filled with water. It is then taken to the place the air of which we wish to test; the water is then emptied out and its place taken by the air. The stopper is then tightly replaced and the flask brought back and again connected with the apparatus. Any impure air that may have entered the apparatus when G was disconnected is got rid of and a test made in the following way: Suppose that 1 c. c. of the air to be tested be the correct amount to be mixed with the pure air in the receiver A; then 1 c. c. of water is allowed to run out of the burette N into the cup M, the level of the water in M having been previously brought to the engraved line on the exit tube. After 1 c. c. of water has been measured into M the stopcock H is opened and the measured quantity of water allowed to enter G. When the water in M falls to the engraved line, H is closed. By this means a cubic centimeter of air is displaced from Q and sent into the tube E. Before this measuring process was done the stopcock F was closed and a stroke of the pump made, so that immediately after the measuring was done and the stopcock H closed, the stopcock F is opened, when, as there is a partial vacuum in the receiver A, the 1 c. c. of dusty air is drawn into A along with a quantity of filtered air. After the air has had time to get saturated, F is closed and a stroke of the pump is made, the micrometer being observed while the air is being expanded, and the number of drops counted on some selected squares. A number of tests are made in this way from which the average number of drops per square millimeter is obtained. From the number so obtained the number in the air tested is calculated. If there be 1 cm. of air above the micrometer then we must multiply the average number counted per square millimeter by 100, and that will give the number per cubic centimeter in the air in the receiver. This number must then be multiplied by the proportion of pure to impure air, and also by the proportion by which the air is expanded by the pump. When this is done we get the number in the air tested. It is not necessary to use always 1 c. c. of air to be tested, but less can hardly be used with any degree of accuracy with this apparatus. The amount should be such as to give not more than 5 drops per square millimeter. If more dust particles be present than give this number we can not be certain that all of them have become centers of condensation and been counted; for when the particles are numerous all do not become active at once but, after the first particles have fallen, the remaining ones may be seen if a second expansion be made.

The method of working above described is only suitable for air that is not very impure, and when we can mix one or a number of cubic centimeters of it with the air in the receiver. For very impure air another plan was adopted. A small gasometer was filled with filtered air, and to this was added a measured quantity of the impure air; the two were then mixed. The filter D and tube E having been removed from the apparatus, the gasometer was connected with the apparatus at the stopcock F. The air from the gasometer was then allowed to flow through the receiver A till it had displaced all the air in it at the time. The stopcock F was then closed, expansion made, the number of drops counted, and the calculations made as before. The following table gives the results of some tests made with this apparatus:

*Number of dust particles in air.*

| Source of air. | Number per c. c. | Number per c. inch. |
|---|---|---|
| Outside (raining) | 32,000 | 521,000 |
| Outside (fair) | 130,000 | 2,119,000 |
| Room | 1,860,000 | 30,318,000 |
| Room, near ceiling | 5,420,000 | 88,346,000 |
| Bunsen flame | 30,000,000 | 489,000,000 |

These numbers are of course very variable, owing to changing conditions, but the figures obtained with the newer forms of apparatus do not differ greatly from these. Although we were prepared to find that, if the number of dust motes in a sunbeam should ever be counted, the number would be very great, yet I imagine to most of us the above figures are almost a revelation, as the visible dust motes do not amount to more than a small fraction of these numbers. These figures show that some of the dust particles must be inconceivably small, almost molecular in their dimensions. Millions in a cubic centimeter, and yet so light that their united mass can not be weighed, and almost none of them visible with the highest powers of the microscope, and yet for the reasons already given these very small particles of matter are not gaseous.

The apparatus shown in Pl. XLI is evidently quite unsuited for everyday observation. That apparatus having shown the possibility of counting the dust particles in our atmosphere, the object of its existence was accomplished and it had to give way to more perfect forms. The next instrument constructed was made on much the same lines, only the receiver was made of a glass cylinder, the bottom closed with a metal plate through which passed the necessary tubes, etc., and the top was covered with a plate of glass. An arrangement was also provided for mixing and saturating the air in the receiver. Many different forms of apparatus were tested for measuring the small quantity of dusty air for mixing with the pure air in the receiver. The most successful of these will be described later.

The apparatus fitted up in the tower of the Ben Nevis Observatory is

constructed on much the same lines as shown in Pl. XLI, only all the apparatus is of metal except the glass covering of the receiver. After a number of observations had been made by me, at low level, in different country districts, it became evident that for instruments to be used for meteorological purposes only, that it would not be necessary to have apparatus for measuring small quantities of air, as the number of particles in country air is never very great. It was found when working in the country that it was never necessary to use less than one-fiftieth of the impure air; and as by means of the air pump used for expanding the air, a method was devised of measuring quantities of impure air down to one-fiftieth, special apparatus for measuring smaller quantities was not necessary. The air pump is simply graduated in such a manner that by drawing out the piston to any particular mark on the scale, we know the proportion of air we have extracted from the receiver. The receiver is then put in connection with the air we wish to test and a quantity of air equal to the amount we pumped out enters the receiver. The pump is provided with checks which can be put in to stop the piston at the desired point, so that the measuring may be correctly and quickly done. The pump and receiver are so proportioned that one full stroke of the pump takes out $\frac{1}{3.33}$ of the air of the receiver. When an equal quantity of the outer air is admitted to the receiver and then expanded to produce condensation the proportion to the outer air is reduced to one-fifth. The other points marked on the scale on the pump show the length of stroke required to extract an amount of air such that when expanded the proportions will be one-tenth, one-twentieth, and one-fiftieth. Thus by means of the pump alone the necessary quantity of impure air may be accurately measured. After the impure air has entered the receiver the stirrer is moved up and down, so as to mix the pure and impure airs, after which one full stroke of the pump is made to expand the air, and the number of drops per square millimeter counted. Attached to the Ben Nevis instrument there is a pipe which goes to the outer air and there is apparatus for keeping up a circulation of air through this pipe past the inlet stopcock of the instrument.

The first portable dust counter is shown on Pl. XLII, figs. 1 and 2. This instrument is capable of testing the very impure air of cities and of rooms, as well as the pure air of the country. In the figure, R is the receiver; it is made of metal and is of a shallow, cylindrical form. A is the air pump and F the filter. The micrometer is shown on the center of the receiver at a distance of 1 cm. from the glass plate closing the top of the receiver. When the micrometer gets bedewed it is cleared by blowing with the mouth through the tube G; this heats the under side of the micrometer and evaporates the moisture. Observations are made with this instrument in ordinary daylight. The diaphragm shown at the same level as the micrometer is the stirrer which is worked up and down to saturate and mix the airs.

When working with this instrument in ordinary country air, the stopcock S is put in the position shown in the figure, and air is pumped into the receiver through the filter F. The stopcock S is then turned one-eighth of a turn to the left to close it, and one stroke of the pump made, when, if there are any dust particles in the receiver, they will become centers of condensation and fall. After this the stopcock is turned back to the position shown, to allow filtered air to enter. In a short time the stopcock is again closed, and if, on again expanding, no drops fall the air will be dust free. Suppose, now, the air to be pure, a test may now be made. To do this, the stopcock is as before turned one-eighth turn to the left and the pump drawn down to the necessary amount, say to one-tenth on the scale; it is then returned to the top of its stroke, and the stopcock turned one-eighth farther to the left; this puts the receiver A in communication with the outer air through the side passage shown on the left side of the stopcock S. After the measured quantity of air has entered, the stopcock is closed, the stirrer worked, the air expanded, and the number of drops counted on some of the squares—say, on four. This is repeated five or ten times, and the average number of drops per square millimeter is taken and multiplied by 100, the number of square millimeters in a square centimeter, and by 10, the proportion of pure to impure air used in the test. Suppose the average of all the tests gave 3.4 drops per square millimeter; that would be 340 per centimeter in the air of the receiver, and 3,400 in the air tested. When the air is very pure (and even one-fifth of impure air gives fewer than 1 drop per square millimeter), then the receiver is filled with unfiltered air alone; this is done by putting the stopcock S a quarter of a turn to the left of the position shown, so as to open the passage to the outer air; the pump is then worked for a number of strokes and an occasional movement made with the stirrer. By this means the receiver becomes filled with air from the outside, after which the stopcock is closed, the stirrer worked, the air expanded, and the drops counted. Suppose the air in this case gave an average of 2.6 per square millimeter; that would be 260 per cubic centimeter in the air of the receiver, but as this air was expanded the above figure must be multiplied by 1.4, giving as a result 364 as the number of particles in the air tested.

Supposing, now, we wish to test very impure air—so impure that, using the smallest quantity we can measure with the pump, namely, one-fiftieth, there are more than 5 drops per square millimeter—then we must use one of the measures shown at M. There was considerable difficulty met with in the first attempts to measure small quantities of air, owing to the fact that if any length of time was taken in the process, or if the air was conveyed through long passages, much of the dust was lost. This was shown by different numbers being obtained if more or less time was taken in measuring. It was therefore necessary, in designing the apparatus, that the process of measuring should be a very rapid one, and that the measures and passages should, so to

speak, be washed out with pure air, so as to remove the last trace of dusty air adhering to their walls. The plan ultimately adopted is very simple and has been found to work very satisfactorily. It is shown at M (fig. 1, Pl. XLII). In the drawing three measures of different capacities are shown. Each of these measures is simply a kind of four-way stopcock. The capacity of the bore in the plug of the stopcock is the measure, and it is made a certain simple proportion of the capacity of the receiver and air pump—that is, of the expanded air—so as to ease the calculations. In the figure the largest stopcock has a capacity of one two-hundredth of the receiver and pump, the next a capacity of one one-thousandth, while the smallest is one five-thousandth.

The following is the method of using these small measures: Suppose on trial we find that the medium-sized one gives the correct quantity of air for making a test. Then this stopcock is turned a quarter turn, so as to connect the two side branches. A full stroke of the pump is then made and the piston returned to the top of its stroke; this makes a partial vacuum in the receiver. An india-rubber tube having been previously attached to one branch of the stopcock, air is drawn through the measure in any convenient way. After the current has been kept flowing for a time, so as to insure that the bore in the stopcock shall be full of impure air, the stopcock is then suddenly turned a quarter turn while the air is still flowing. This movement at once opens the passage between the receiver and the filter, and dustless air rushes through the measure and carries the measured quantity of dusty air with it into the receiver, at the same time clearing the passages of any adhering dusty air. After this the stopcock is closed, the stirrer worked, the air expanded, and the number of drops counted. This time the average number of drops is multiplied by 100, as before, and then by 1,000, the proportion of air used. The instrument when in use is supported on a tripod stand, the head of which is shown at T. Fig. 2, Pl. XLII, shows another arrangement for fixing the apparatus to the tripod. As before, A is the pump; to the lower end of the pump is attached a strong tube, B, the lower end of which is screwed firmly to the tripod head. The pump is worked by the sliding sleeve C. The small tube D screws into the end of the filter F and is tied at the foot to the pump support, to keep all firm. By this arrangement the tripod legs are of a convenient length to form a walking stick, and the whole apparatus is also more easily worked. The portable apparatus can be taken to pieces for easy carriage. The air pump unscrews at E; the stopcock S also unscrews from the receiver. The "battery" of small measures forms one piece and the filter another, and all are packed into a case 8 by 5 by 3 inches. This instrument can test air of any impurity up to 2,500,000 particles per cubic centimeter.

After some experience with the portable apparatus, certain weak points made themselves evident and occasionally gave trouble. These defective points were: First, the silver micrometer; some observers

found difficulty in keeping the polished surface in good working condition; second, the air-pump valves occasionally gave way; third, leakage occasionally occurred where the stirrer rod passes through the bottom of the receiver. Further, after many thousands of observations, it became evident that in unpolluted air the apparatus for measuring small quantities was quite unnecessary. The whole apparatus could, therefore, be very much reduced in size if only to be used for meteorological work. After a number of experiments had been made to test the different points, another form of the instrument was designed. This new form is shown in Pl. XLIII, which represents the pocket dust counter drawn full size. The capacity of the receiver is only one-fifth that of the portable instrument. When taken to pieces it packs into a case about the size of a well-filled cigar case and weighs 8 ounces. This instrument can test air of any impurity up to 25,000 particles per cubic centimeter.

On looking at Pl. XLIII it will be seen that the instrument is much simpler than the portable one. It will be noticed that there is no filter; further, there are no air-pump valves to give trouble, nor is there any possibility of leakage at the stirrer rod, as it does not now come through the bottom of the receiver; but perhaps the greatest improvement is in the use of glass for the micrometer. In Pl. XLIII, figs. 1 and 2, R is the receiver, P the pump, and K a stopcock, which does the work of the air-pump valves and of the stopcock S in the portable instrument; and it does the double duty with no more trouble to the operator than the stopcock S. M is the lens for observing and counting the drops. It is found that a simple lens of 2 cm. focus does very well for this purpose. G is a guide tube screwed into the pump cover; on this tube slides a sleeve which is fixed to the piston rod. On the guide tube G is engraved the scale showing the proportions of air measured by the pump. This scale is shown at fig. 4.

As previously explained, the great difficulty in using glass for the micrometer was that the drops were nearly invisible on it. After some trouble a method of illumination was devised to overcome this difficulty, and the plan is shown in figs. 1 and 3. It consists simply of an ordinary mirror with a round black spot in the center. By this arrangement, while the mirror illuminates the micrometer and anything resting on it, the field of view of the lens is quite black. The result is that the small drops are distinctly seen shining brightly on the dark ground, and counting can be easily done, and can be done in weaker light than is possible on a silver micrometer. The bottom of the receiver and both sides of the stirrer are covered with blotting paper to hold water to saturate the air.

We shall now describe the manner of working this instrument. As we have now no filter to purify the air in the receiver, we must get rid of the dust particles in some other way. This is done by simply drawing down the piston to expand the air in the receiver; this causes a

cloudy condensation, and some dust particles fall; the piston is then put back and in a short time the air is again expanded, when more particles become centers of condensation and fall. This process is repeated till all the dust particles have fallen and the air remains free from drops when expanded. If no drops fall on expansion we know that the air is dust free and that there are no leaks in the fittings of the instrument, so that we can now proceed to make a test. The first thing to be done is to measure into the receiver the required quantity of the air to be tested, but before doing this the stopcock K should be turned a quarter turn to the left, so as to put the receiver in communication with the outer air and allow any surplus pressure, due to leakage while purifying the air, to escape. The stopcock K is then returned to the position shown in fig. 1, and the air pump drawn down to say $\frac{1}{10}$ on the scale; this takes a quantity of air out of the receiver. The stopcock K is now turned a quarter turn to the left, so as to put the receiver into communication with the outer air, when a quantity of impure air, equal to the amount pumped out, rushes in; at the same time the pump is emptied by pushing back the piston, the air escaping through a small side passage drilled in the plug of the stopcock, as shown in fig. 2. When the receiver is in communication with the outer air the front of this passage opens to the pump, as will be seen from fig. 1. After this the stopcock is returned to the position shown in the figure, and the instrument is turned upside down, to cause the stirrer to fall, then brought back to its original position. This is done a few times to mix the airs thoroughly. The stirrer is shown in figs. 1 and 2. It looks, in the drawing, like a horizontal diaphragm near the bottom of the receiver. After the airs have been mixed and saturated, the mirror is adjusted to give the best illumination, the pump quickly drawn down, and the drops counted, as in the other instrument. Preparations are then made to repeat the test. This is done by returning the piston to its first position, and in a short time again expanding the air; this time a few drops may fall, since the air that entered the pump may not lose its dust, owing to the high temperature of the pump due to contact with the hands of the observer. When the drops have ceased falling when expansion is made it will likely be found that the micrometer requires attention. Some drops will be seen on its surface. To remove these, the under side of the micrometer is touched with the tip of a finger and a stroke of the pump made to expand the air and assist the evaporation of the drops. Care must be taken not to heat the micrometer too much, otherwise the drops in the next test will evaporate in the hot layer of air resting on the micrometer or they will evaporate so quickly on touching it that correct counting will be impossible. After this the instrument is in a condition for repeating the test.

When working in very pure air, when one fifth of it is too little, the stopcock K is turned so as to put the receiver into communication with the outer air, and air drawn out of the receiver through the stopcock

A. The current is kept up till the outer air has displaced all the air of the previous test, after which the stopcock K is turned back to its original position and A is closed. The instrument is then turned upside down two or three times to work the stirrer; expansion is then made, the number of drops counted, and the calculation made as when using the portable instrument. With the first portable and the first pocket dust counters many thousands of tests have been made, and both instruments are still in first-rate working order. The former has given very little trouble, and the latter none; beyond the necessary cleaning of the micrometer and an occasional drop of oil to the air pump, nothing has been required.

The last instrument I have constructed for testing the dust in the air is the koniscope. The koniscope is not, however, an instrument of precision like those previously described. Its construction was suggested by some experiments in which I found when cloudy condensation was rapidly produced in dusty air, either by mixing steam with it or by rapidly expanding it when saturated, that the light transmitted through the cloudy air was colored, and that the color of the transmitted light was determined by the size of the cloud particles, and the depth of color indicated the number present. Though the koniscope be not an instrument of precision, yet it has its advantages. It is easily kept in order, anyone can use it, as no special training is required, and tests are quickly and easily made with it—recommendations of no small value in an instrument for practical uses.

The koniscope consists of a long metal tube with glass ends, and connected with an air pump. The tube in most of the instruments made is 1.5 cm. diameter and 50 cm. long. The inside of the tube is lined with blotting paper to hold water to saturate the air. The air pump is 2.5 cm. diameter and 14 cm. stroke. It is attached to one end of the tube in such a manner that the water in the tube has a difficulty in finding its way to the pump. At the other end of the tube is a stopcock for admitting the air to be tested. It is convenient to have a small chamber at the eye end of the tube, into which projects the eyepiece, which consists of a short tube with a glass end. By this arrangement the glass end is kept dry. The other end of the tube is closed by means of a piece of ground glass.

In using this instrument, the first thing to be done is to see that the inside of the tube is wet, and when beginning testing there should be as much water in it as will just run slowly from end to end when the tube is tilted. The instrument is then taken to the place where we wish to test the air, the stopcock is opened and two or three strokes made with the air pump to fill the tube with the air to be tested. The stopcock is then closed, the instrument held up to the eye and pointed in the direction of any light, and one stroke of the pump made quickly. At the moment of expansion the light transmitted through the tube will be observed to change. If very little dust be present only a slight

diminution of the light, with but very slight color, will be seen; but if there be much dust in the air the color will be deep, and if very impure, as when collected from the products rising from a flame, the light will have an intensely deep color, or be entirely cut off. For one full stroke of the pump the color depends on the number of particles present. If there be few particles in the air the color at the beginning of the stroke is light blue or green, and the color changes to yellow as the expansion increases; then a second blue and green appear, finishing at the end of the stroke with yellow. If many particles be present, only the first series of colors appear, and the colors are deeper; but if the air is very impure only the first blue may make its appearance and the color will be very deep. It is the depth of the first blue that is used as an indication of the purity, or rather impurity, of the air tested. The indications of the koniscope have been compared with the numbers given by the dust counter when testing the same air, and the following table shows the number of particles that produced the different depths of color:

| Dust counter, particles per c. c. | Koniscope, depth of color. |
|---|---|
| 50,000 | Color just visible. |
| 80,000 | Very pale blue. |
| 500,000 | Pale blue. |
| 1,500,000 | Fine blue. |
| 2,500,000 | Deep blue. |
| 4,000,000 | Very deep blue. |

From the above figures it will be seen that the koniscope is not for testing air of ordinary purity, as the lowest point in its scale is a very high number, namely, 50,000 particles per cubic centimeter. It is only intended for sanitary purposes, for the detection and rough estimation of the impurity introduced into the air by gas flames, etc. The method of using it is, first, to test and note the depth of color given by the air outside, or wherever the supply for the room is drawn from. Any increase from that depth of color given by the air from any part of the room indicates pollution, and the amount of the increase in the depth of the color indicates the degree of pollution. By means of this instrument the gradual pollution of the air in rooms while in use is easily observed. The direction of the air currents in rooms when gas is burning may be shown by means of it; also the gradual descent of the lower limit of impure air near the ceiling, and the manner and amount to which this upper impure air mixes with the incoming purer air.

Turning now to some of the results obtained by the use of the dust counter: First, what is the actual number of particles present in air? As might be expected, the numbers vary greatly according to the conditions surrounding the place where the tests are made. Observations show that the number may vary from almost nothing to hundreds of thousands per cubic centimeter. Tests have been made by myself for the last four and a half years at a number of places, in the South of

France, at the Italian lakes, in Switzerland, Scotland, and other places. A great number of observations have also been made by the Scottish Meteorological Society, at their observatory on Ben Nevis.

At none of the places on the French Riviera has the number of particles ever been observed to fall much below 1,000 per cubic centimeter, the lowest observed being 750 per cubic centimeter, while the number was frequently some thousands. The numbers were much the same at the Italian lakes; the lowest observed being about 600 per cubic centimeter, the number generally rising to some thousands. For the last five years observations have been made for about a week in May of each year on the Rigi Kulm, in Switzerland. The following table gives the highest and lowest readings obtained in the different years, and the number of days on which tests were made in each year:

*Dust particles on the Rigi Kulm.*

| Year. | Number of days. | Highest. | Lowest. |
|---|---|---|---|
| 1889 | 5 | 2,350 | 210 |
| 1890 | 6 | 9,500 | 375 |
| 1891 | 7 | 4,200 | 326 |
| 1892 | 7 | 13,750 | 550 |
| 1893 | 7 | 16,500 | 441 |

During the last four years observations have been made in July at Kingairloch, a house situated in the wilds of the West Highlands of Scotland, and far from other dwellings. The following table gives the highest and lowest readings obtained there in the different years, and the number of days in which observations were made:

*Dust particles at Kingairloch.*

| Year. | Number of days. | Highest. | Lowest. |
|---|---|---|---|
| 1889 | 14 | 4,000 | 205 |
| 1890 | 28 | 7,600 | 16 |
| 1891 | 29 | 7,600 | 34 |
| 1892 | 28 | 6,200 | 38 |

These two tables show the comparative purity of the air on the Rigi Kulm and at Kingairloch, and show the air at the latter station to be much the purer. Other observations made at different parts of the West Highlands also show the air of that district to be remarkably pure. The lowest numbers observed at Kingairloch are much lower than the lowest observed on the Rigi. These figures, however, do not represent the relative purity of the airs of the west of Scotland and of Switzerland, as the Rigi observations were made at an elevation of 6,000 feet, while Kingairloch is at sea level; the one in the pure upper air, and the other in the comparatively impure lower air, and further, the observations taken at Kingairloch are liable to error in the maximum numbers, owing to local pollution, which it is impossible always to avoid at low levels, while it can be avoided at high ones. If we

compare the figures on the Rigi Kulm with those obtained by Mr. Rankin on Ben Nevis, a better idea of the greater purity of the air of the West Highlands will be obtained. At the latter station air has been observed in which scarcely one particle per cubic centimeter could be found, and Mr. Rankin says in the Journal of the Scottish Meteorological Society, Vol. IX: "It may be stated that any number over 4,000 is phenomenally large, and any number less than 100 phenomenally small." Now, on the Rigi nothing under 210 has been as yet observed, and 4,000 is far from being a phenomenally large number at that station.

As to what the number is in cities, it is impossible to say anything definite, so much depends on where the observations are made; as we are always near sources of pollution, the air must be very unequally polluted. In Paris observations were made in the garden of the meteorological office; the number was as high as 210,000, but, as it is always difficult to tell how near we are to active chimneys in cities, all such observations have but little value. In Victoria street, London, 150,000 were observed, and in the air coming direct from Battersea Park the number was generally a little over 80,000, and in one test showed 116,000, a strong westerly wind blowing at the time.

It would be impossible for me in the space allowed to give all the conclusions indicated by a study of the figures obtained by means of the dust counter. Little more can be done than to indicate some of the points to which attention has been given. One conclusion clearly indicated is that haze in our atmosphere greatly depends on the amount of dust present, and that the hazing effect of the dust is influenced by the humidity. An examination of the figures shows how these two influences work together to produce haze.

The hazing effect of the humidity does not appear to be a direct effect of the water in a gaseous state, as air with a large amount of vapor in it, and almost saturated, has been observed which was clear, owing to the amount of dust being extremely small. Further, if vapor acted as vapor—that is, in the gaseous state—in producing haze, then the hazing effect of the vapor would be directly proportional to the vapor pressure at the time. So that if a winter day could be hazed with vapor, no summer day could ever be clear, as there is always more vapor on a dry summer day than on a damp winter one. We know that haze is much more nearly proportional to the relative than to the absolute humidity, so that it is not so much a question of quantity of vapor as of nearness to the condensing point. The hazing effect of the vapor, or, to be more accurate, of the suspended water, seems rather to be the result of the dust particles condensing some vapor on them, and thus increasing their size. An examination of the dust observations indicates that the condensation of the vapor on the dust takes place even when the air is what we call dry—that is, while the air is in a condition to show a difference of some degrees between the dry and wet bulb thermometers.

Direct observations on dust collected from the atmosphere show that it has the power of condensing vapor out of air which is far from being saturated, and that the amount condensed by the dust increases with increase of humidity. The dust particles while floating in the air seem also to have this condensing power. Even when the wet and dry bulbs show a considerable degree of difference, some water seems to be condensed on the dust; and when the air cools and the humidity increases, more and more vapor is condensed on the particles. They thus increase in size and in hazing effect, and before the air is quite saturated the hazing effect of the dust and of the vapor condensed thereon is very great. The dust and haze observations show that the amount of vapor so condensed depends on the relative humidity, and also to a certain extent on the absolute humidity of the air. From this it is evident that when we wish to test the hazing effects of dust, we must compare only days having as nearly as possible the same relative humidity and also the same dry-bulb temperature. The more recent observations have not yet been worked out, but the following figures from the observations of 1889 show the result of such a comparison when the wet-bulb depression was 4°.

| Number of particles. | State of the air. |
|---|---|
| 550 | Clear. |
| 814 | Medium. |
| 1,000 | Thick. |
| 1,900 | Do. |

The observations on the Rigi Kulm show the hazing effect of dust very clearly. An examination of the observations at that station show that on all the very clear days the number of particles was under 1,000 per cubic centimeter, and that the thickness of the haze increased with the increase of the particles. The observations made on the haze between Hochgerrach and the Rigi bring out this point very clearly. Hochgerrach is a mountain situated at a distance of 70 miles from the Rigi, in an easterly direction, and from the amount of haze on it we get a very good estimate of the clearness of the atmosphere at different times. During the five visits to the Rigi, Hochgerrach was visible thirteen times. On eight of these occasions the mountain was only from one-fifth to one-half hazed, and the number of particles varied from 326 to 850. It was seen five times when the number varied from 950 to 2,000, but on all these occasions the mountain was little more than just visible. It was never seen when the number was over 2,000, however dry the air might be; and the one occasion on which it was seen when there were 2,000 particles in the air the transparency was greatly due to the very low temperature at the time. The air is not always very clear when the number of particles is low; but it is also necessary, in order that it be very clear, that the relative humidity be not high.

In January of this year (1893) I communicated to the Royal Society of Edinburgh the results of some observations made in another way on the hazing effect of atmospheric dust. Having established that the hazing effect of dust is proportional to the number of particles, and that though the action of the dust is intensified by the humidity, yet for the same humidity the hazing is proportional to the amount of dust, and having also shown by the dust counter that air coming from inhabited districts was very dusty compared with that blowing over uninhabited ones—it thus appeared that if we compare the haze in air coming from inhabited areas with that coming from uninhabited ones, and compare only days on which the humidity was the same, that we might get some information regarding the hazing effect on our atmosphere produced by the presence of human dwellings. Falkirk is very favorably situated for an inquiry of this kind, as all winds coming to it from W., NW., and N. are pure, as they blow over a mountainous and thinly inhabited area, which extends across Scotland to the shores of the Atlantic; whereas in all other directions the air comes to Falkirk from thickly inhabited districts.

The observations made for this investigation consist of observations of the direction and force of the wind, temperature of the wet and dry bulbs, and the amount of haze at the time. The amount of haze was estimated by observing the haze on distant hills, and all these observations were reduced to a common scale by calculating from the observations the extreme limit of visibility at the time. Of the observations, 200 were available. These were arranged in tables. All the observations when the wet-bulb depression was 2° were entered in one table; all the observations when the depression was 3° in another, and so on. In this manner the airs coming from different directions were compared as to haze when their humidity was the same. The conclusions arrived at from an examination of the figures in these tables are, first, that when the wind blows from certain directions it is more than six times clearer when damp and more than nine times clearer when dry than air from the other directions; second, allowing for a slight amount of impurity thrown into the air in the pure areas, the air at Falkirk, for all but the W., NW., and N. winds, is nearly ten times more hazy than if there were no inhabitants; third, the transparency of the air increases with the dryness, being about 3.7 times clearer when the wet-bulb depression is 8° than when it is 2°—that is, the clearness is roughly proportional to the wet-bulb depression. The maximum limit of visibility observed in air from the pure directions was 250 miles, while for the impure directions it only rose occasionally to 50 miles when the air was very dry.

The amount of dust in the atmosphere, as might be expected, is greatly affected by the wind. It is found that the amount of dust at low levels varies with the force, as well as with the direction of the wind. As the wind falls the number of particles rises, and vice versa. At high elevations, however, high winds frequently increase the number

of particles by driving the valley air to the upper level. Winds blowing from populated districts carry their dust with them to great distances. The dust observations give good reason for supposing that the dust may be carried many hundreds and probably thousands of miles.

Observations made with the dust counter on the Rigi Kulm show that there is a daily variation in the number of particles in the air at the top of the mountain. The number for most days rises very considerably during the day, generally beginning to rise before midday, and attains its maximum in the afternoon. The afternoon number is often as much as four or five times the morning one. The hour at which the impure air begins to arrive at the top of the mountain varies according to the weather as regards clouding, etc. If the wind blows from a pure direction, this afternoon maximum may not take place, as the increase in dust is due to the rising of the valley air after it has been heated by the sun. If the wind blows from the Alps the number on the Rigi during the day does not vary much, owing to the air of the valleys in the Alps being pure, but whenever the wind blows from populated areas the rise takes place. This up and down movement of the valley air is also clearly brought out by the Ben Nevis observations. Mr. Rankin shows it is much influenced by the type of weather at the time. The Ben Nevis observations also show that the months of March, April, and May are the dustiest months of the year at that station. The reason for this probably is that these are the months when the temperature of the air is rising rapidly. The Ben Nevis and Fort William temperature observations show that these months are also those for which the difference between the mean temperatures at high and low levels is the greatest; there is, therefore, during these months the maximum tendency to the formation of ascending hot currents carrying the impure valley air to the top of the mountain.

In autumn, when the upper air has become warmer and the sun's heating power is less, there is not the same tendency to the formation of these ascending currents. At Ben Nevis the winds from E., SE., and S., are the dustiest; they are also the dustiest at low level at Kingairloch; this is partly owing to the fact that the populous districts of Scotland lie in these directions from both stations at a distance of about 60 miles.

Many of the observations on dust point to the conclusion that there may be a relation between the number of particles and the climate; a high number is frequently accompanied by a high temperature and exceptionally cold periods by very low numbers, but many more observations are necessary before so important a conclusion can be accepted.

It has been observed that in fogs the number of dust particles is very great, and it is thought that the great number of particles aids in producing the fog by enabling the air to radiate its heat more freely, and so become cooled quickly below its dew point. In a communication made by me this year to the Royal Society of Edinburgh, it is

shown that there is a great difference in the action of different kinds of dust particles in producing fogs. In ordinary country fogs the dust particles are similar to those in clouds. In both these cases it is shown that the water particles formed on them tend to be few, and if the condensation be made quickly, so that many water particles are formed, that a process of differentiation afterwards takes place; the smaller particles evaporating and the larger ones increasing in size, owing to the difference of vapor pressure at the surfaces of drops of different sizes. This differentiating process causes some of the water particles in fogs and clouds to grow to such a size that, with the aid of the dust counter, they may be seen falling. In this way clouds and ordinary fogs tend to rain themselves out of existence. Not so a town fog in which many of the particles which form the nuclei of condensation have an affinity for water. This affinity is fatal to differentiation of the particles, and by checking it prevents the natural decay and falling of the water particles. Air with dust particles having an affinity for water tends to produce a maximum number of small water particles, with but little tendency to fall. While, if there be no affinity, the tendency is to produce a minimum number of large particles with a tendency to fall. The one kind of dust particle forms a persisting fog, while the other forms a fog with a tendency to rain itself away. This difference seems to account for the greater thickness and persistence of town fogs.

These are some of the points connected with atmospheric dust to which attention is at present being directed, but many others are being worked at and doubtless there are many more unthought of. At present what is wanted is more observations of the number of dust particles, under different conditions of climate, etc., and in different parts of the globe. As yet these observations have been much too local. The greater part of this field of inquiry is almost unworked, and calls for more attention, and it appears likely to reward those who cultivate it.

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## 20.—THE STUDY OF THE UPPER ATMOSPHERE FROM OBSERVATIONS ON MOUNTAIN STATIONS.

J. Hann.

The investigations of the physical conditions and the processes in the upper layers of the atmosphere demand either observations in balloons or at fixed meteorological stations on high mountains. The former, or the observations during balloon voyages, certainly have certain advantages compared with those made on mountains, and in particular much greater altitudes can be reached than on mountains; yet observations made in a balloon have many disadvantages. It is not likely that we shall be able in the near future to make a long

series of meteorological balloon records at a definite altitude. Even with a captive balloon this is only practicable to a very limited extent, and only for low altitudes as it is impossible to secure uniformly an invariable altitude; observations of the atmosphere in captive balloons have therefore very limited value. Since a free balloon is carried along by the air currents, anemometric observations are necessarily out of the question, and we get but fragmentary indications of the air currents at definite times. The conditions of the upper atmospheric layers during all states of the weather and for any elevation whether during storms, heavy precipitation, thunderstorms, etc., can only be ascertained from fixed stations on mountain peaks.

No doubt meteorological observations in balloons, especially for the exploration of the highest attainable strata, have a bright future before them, and hold out great promise for meteorology; nevertheless they can not supersede the fixed meteorological stations on elevated peaks. On the contrary, as already remarked, a whole series of investigations is possible at the latter, for which observations in balloons could not furnish any material.

What conditions, then, shall high-altitude observatories satisfy in order that such observations be procurable as shall throw light in the most general way on all meteorological processes in the higher strata? I will not here speak of the outfit respecting the diverse meteorological instruments and physical apparatus, since this appears quite superfluous. A first-class mountain observatory should necessarily be provided with the most approved modern apparatus, and, as a matter of course, with means of continuous registration of the meteorological element, as well as for direct reading by the eye.

More important is the choice of the locality where the station should be located, in order that it may promise the greatest advantage for meteorology.

Fixed meteorological stations for the study of the processes in the higher strata of the atmosphere should be placed on the most isolated mountain peaks, in order that currents of air in the free atmosphere at the same level be least disturbed by the mountain, and at the same time permit of a recognition of the true temperature relations of the strata of air at this altitude—that is, they should not sensibly be affected by radiation either through heating or cooling of the earth's surface.

Since a fairly isolated mountain peak is continually within the influence of a large and freely movable mass of air, and but rarely subjected to stagnation, the above condition is much easier to satisfy than might at first be imagined. The strata of air in contact with the mountain top and cooled during the night by radiation will descend the slope by reason of their greater specific gravity, and hence will not affect the indications of a thermometer suspended several meters above the surface. If the mounting of this instrument is attended to with

the greatest of care we can easily, on an isolated mountain summit, get temperatures that are the same as those of the stratum of equal altitude. Air currents will be strongly influenced, even if the anemometer is advantageously located, but the effect on the velocity will be more decided than on the direction. Anemometric registration at high elevations still remains the only means to make evident, and continually follow up, the relations of the air currents at certain altitudes with a view of comparing the amount of air transported by the winds for certain intervals of time, and in particular during a whole year.

The altitude above the ocean of the observatory should be determined by direct leveling (and not merely barometrically), and with an accuracy of $\pm 0.1$ meter. This will enable us to assign due value to the observed atmospheric pressure, and besides will admit of various investigations of a physical nature.

Particularly valuable would be barometric observations made on mountain peaks most directly rising from the ocean, as, for instance, Mount Etna, Pic de Teyde, Fusiyama, etc., for which places the magnitude or thickness of the air stratum which lies between the level of the ocean and the top of the mountain is given with sufficient accuracy. This is not the case with inland places, in consequence of the irregular contour of the earth's surface at the foot of the elevated station. It is not possible to determine with certainty the variations in barometric pressure on mountain tops by reason of the variable effect of the air stratum below the top and its consequent expansion or contraction, a circumstance which occasions much uncertainty in the calculations.

It is easy to see that such isolated mountain tops may also be very suitable for other purposes than that of erecting observatories.

Particular attention is to be paid to the correction of the barometer at the high stations and its changes, if any, should be ascertained with accuracy; consequently, there ought to be several barometers at each observatory. Their comparison must be made at the mountain observatory itself.

If the altitude of the barometer has not become known through a geodetical leveling the exact knowledge of the constant corrections of the instruments will have less importance; on the other hand, it is a matter of importance that the correction should not change, or, at least, that any changes be carefully looked after. The air-pressure observations should form a perfectly homogeneous series, but if not the means for rendering it homogeneous should be given, in that all alterations in the barometers and their elevations may be carefully recorded.

Elevated stations will serve their purpose most satisfactorily when supplemented by a base station well selected at the foot of the mountain, and a further advantage will be gained if other intermediate meteorological stations can be established where at least observations of temperature can be secured; hence, besides the top and base stations, there ought to be several intermediate stations, in order to obtain full

knowledge of the condition of the stratum of air lying between the upper and lower levels. How essential this may be is shown by an example in our latitude. During winter we frequently find that within the regions of a barometric maximum during clear, calm weather the lower elevations, and particularly the valleys, are subject to heavy frost, especially in the presence of a cover of snow. Frost also occurs at high elevated peaks, as, for instance, on the top of the Sonnblick, at an altitude of 3,100 meters, though often it is less severe than in the valleys. The top of the Sonnblick has occasionally at such times (even at night) a higher temperature than the valleys at its base (in 600 to 800 meters elevation). We would, however, be very much mistaken if in such cases we should take the mean temperature of the air stratum between 600 and 3,100 meters as equal to that derived from the mean temperatures observed at the top and bottom.

The observations at intermediate heights, say from 800 to 2,000 meters and above, indicate for such cases that the intermediate stratum of air possesses a much higher temperature, which is not infrequently above the freezing point. In the absence of these intermediate stations, we should have been left in entire ignorance of this interesting and theoretically important fact. For example, the variation of temperature when measured in the vertical direction (in degrees centigrade), in the Salzburg district (in the region of the Tauern), was found to be during the month of January, 1887, $t_h = -8.3^\circ + 0.902\, h - 0.0536\, h^2$, where $h$ equals the relative height in hectometers of the valleys at the foot of the Sonnblick (about 850 meters, i. e., 8.50). A column of air of 1,680 meters thickness had a higher temperature than that of the air in the valley and than that of the air at an elevation above 2,500 meters. The mean of the temperatures as observed at the low level of 850 meters ($-8.3^\circ$ C.) and at the top in 3,100 meters ($-12.6^\circ$ C.) would be $-10.4^\circ$, but in reality the mean temperature of this stratum of air of 2,250 meters thickness was only $-7^\circ.3$, or more than $3^\circ$ higher. It was only by means of the intermediate stations between the highest or top station and the lowest or valley station that this peculiar temperature distribution could be made evident. Cases of this kind are frequent in winter, when these thermal stratifications are present.

The establishment of intermediate stations is therefore a matter of importance. They should be located, as far as practicable, not in closed valleys, but on mountain spurs, or, still better, on lower peaks. Their ideal distribution would be over a series of adjacent mountain tops at different altitudes.

The temperature of the air strata lying stagnant or motionless in the valleys is frequently of a local character, and the same is true respecting the distribution of moisture. These strata are, especially in summer, relatively too warm, and in winter too cold.

The location of the extremely interesting and important station of great altitude on Pikes Peak, 4,308 meters above the sea, had the

defect of not being supported by a base station nor by intermediate stations. The observations, therefore, do not admit of a reliable conclusion respecting the vertical distribution of the temperature, and it is not possible to make use of the temperature observations on Pikes Peak for the elucidation of the question of the vertical temperature distribution during cyclones and anticyclones, for which purpose they would otherwise have been so important.

It must, therefore, be admitted that the presence of at least one or two intermediate stations between the top and base stations is of great importance in order that we may secure the full scientific value of the observations made at high elevations.

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## 21.—THE STUDY OF THE UPPER ATMOSPHERE BY MEANS OF CLOUD OBSERVATIONS.

Dr. Vettin.

In that I receive an invitation to contribute a paper on the study of the upper atmosphere by means of cloud observations, I attribute the honor implied therein to the fact that, at a time when investigations of this nature were rarely undertaken, I was the first one to make a comprehensive and systematic attempt to determine the movements of the air within our atmosphere by means of cloud measurements.

After determining from two years' continuous observations, made between April, 1872, and April, 1874, whenever occasion offered, the direction, height, and velocity of a number of clouds, I was able to fix the numerical values of certain phenomena, of which I had obtained a superficial knowledge through former observations. I then resumed the observations during a third year, from May, 1877, to May, 1878, and found that they did not materially change the results arrived at from the former series.

The results which I have here in mind are, in my opinion, of importance in the utilization of cloud observations in general, and may be stated as follows:

(1) Clouds are not irregularly distributed through the atmosphere; but they are separated by intermediate spaces, whose magnitude increases continually in a vertical direction.

(2) Above the region of winds there exist five such cloud strata, each one of which has a fixed mean elevation.

The lowest stratum lying above the wind region, "the lower clouds" (*das untere Gewölk*), elevated fog, stratus, according to Hildebrandson, has a mean elevation of 1,600 feet; the second stratum, "clouds" (*Wolken*), cumulus, 3,800 feet; the third, "small clouds" (*Wölkchen*), low alto cumulus, 7,200 feet; the fourth, "lower cirrus" (*unterer cirrus*), high alto cumulus, false cirrus, about 13,000 feet; the fifth and

highest, "upper cirrus" (*oberer cirrus*), cirrus, fine cirro-cumulus, 23,000 feet mean elevation.

In these five strata, which may also be recognized in the trigonometrical measurements made at Upsala by Messrs. Ekholm and Hagstrom,[1] the atmospheric pressure is about as follows:

| Surface of earth. | 1st | 2d | 3d | 4th | 5th stratum. |
|---|---|---|---|---|---|
| $760^{mm}. \times 1.00$ | $\times 0.94$ | $\times 0.86$ | $\times 0.75$ | $\times 0.60$ | $\times 0.40$ |
| $\Delta$ I | 6 | 8 | 11 | 15 | 20 |
| $\Delta$ II | | 2 | 3 | 4 | 5 |
| $\Delta$ III | | | 1 | 1 | 1 |

(3) As indicated by the above, the clouds change their form in so characteristic a manner that their mean elevation (especially that of the three lower strata) can be determined with great certainty from their external appearance alone.

(4) The elevations of the cloud strata, as given above, represent the annual means. They change with the seasons. The strata rise as the weather grows warmer, and reach their greatest mean height in summer; they sink as the weather grows colder, and reach their lowest mean height in winter. The relative height of all the strata remains the same during this rising and falling, a fact that has also been observed by Messrs. Clayton and Fergusson, of Blue Hill Observatory.[2]

For the mean of the year the heights of the five strata, calling that of the lowest 1, are proportionately as follows:

1 : 2.4 : 4.5 : 8.2 : 14.4.

The heights of the first four strata during summer and winter were:

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| Summer | 1,730 ft. | 4,180 ft. | 7,630 ft. | 14,400 ft. |
| Proportion | 1 : | 2.4 : | 4.4 : | 8.3 |
| Winter | 1,410 ft. | 3,170 ft. | 6,290 ft. | 11,700 ft. |
| Proportion | 1 : | 2.3 : | 4.3 : | 8.3 |

(5) The projected velocities[3] of the clouds (i. e., the velocities which clouds would have if they floated in the zenith and at an arbitrarily but permanently adopted elevation, 1 mile, for instance) were as follows, in feet per second, for an adopted mean of the altitudes of the five strata, beginning with the lowest one:

600 216 123 83 57

or about in the proportion of 10:3.5:2:1.5:1. The latter proportion, 1.5:1, for lower and upper cirrus, is especially important. The whitish cirrus clouds in general can readily be distinguished from the lower grayish water clouds; but to correctly assign cirrus to the upper and lower layers merely by their appearance is, in my opinion, mostly impossible. The projected velocity, however, will generally lead to the

[1] See Met. Zeitschr., 1890, Ref. (92).

[2] See Annals of Astron. Obs. Harvard College, Vol. XXX, Part III, 1892, p. 231.

[3] Meteorol. Zeitschr., 1883, p. 92.

desired result. If two kinds of cirrus are observed at the same time, moving in about the same direction, whose projected velocities are about in the proportion of 3:2, it may be assumed with almost absolute certainty that the seemingly slower moving clouds belong to the upper and the other to the lower kind of cirrus. During the three years referred to, I observed 261 cases where cirrus clouds of different velocities were in sight at the same time. The sum of the 261 projected velocities of the faster kind was 25,214, and that of the slower 16,403. These sums are almost exactly in the above-mentioned proportion of 1.5:1. The projected velocity constitutes one of the most useful determinations. It can be quickly found for every cloud; knowing the height of a cloud, its actual velocity, or knowing the velocity, its actual height may be easily calculated. At the same time these velocities serve as trustworthy guides through the labyrinth of clouds. In windy weather especially there is a constant passage overhead of complex cloud masses. If their projected velocities are measured occasionally, at convenient moments, it will readily be seen how the resulting values arrange themselves into groups, how clouds of similar appearance show nearly the same values; and one obtains at the same time an insight into the temporary structure of cloud layers.

For instance, the following projected velocities, in feet per second, were obtained:

| Date: Nov., 1883. | 1. Stratus. | 2. Cumulus. | Low alto cumulus. | Lower cirrus. | Upper cirrus. |
|---|---|---|---|---|---|
| 20 | 435<br>614<br>581 | 812<br>886<br>895 | | 148<br>184<br>143<br>143<br>178 | 107 |
| 21 | 690<br>650 | 855<br>816 | 234 | 121 | 83<br>85<br>94<br>82.5 |
| 22 | | | | 120<br>126<br>117<br>126 | 95<br>94 |
| 23 | 500 | | | | |
| 24 | 265<br>262 | | 128<br>124 | | |
| 25 | 698<br>530 | 838<br>457 | 129<br>125 | 114<br>102 | 52.7 |

It is therefore especially desirable that we should be able to calculate the projected velocity in the most expeditious and convenient manner possible.

If only to save the eyes, it is advisable in necessarily continuous observations, especially in trigonometrical measurements, not to sight the cloud point directly with the eye, but to use a camera obscura, which should be attached to the theodolite in place of the telescope or

sighting rod. The camera may be fitted up like the one described in the Meteorol. Zeitschr., 1883, p. 93, but without a pendulum, as the vertical circle renders the latter unnecessary. Bring the cloud point to the center of the circle on the glass plate; count the seconds it takes the latter to reach the periphery of the circle, and then set the index at the place where the cloud point crosses the periphery. All necessary angles may then be read off on the theodolite, and every such measurement furnishes at the same time the data for determining the projected velocity. Calling the latter C′, the height of the plane of projection H′ (24,000 feet, for instance), the measured height H, and the actual velocity C, we have $C=\frac{C'H}{24,000}$ feet per second; and (with a measured shadow velocity, for instance) $H=\frac{C\times 24,000.}{C'}$

In the atmosphere the air is constantly in motion and the study of the upper atmosphere depends principally upon the accurate determination of this motion as regards time, direction, velocity, and volume. A multitude of problems confront us awaiting solution, but in the end these are all united into the one great problem of the circulation of the atmosphere between equator and pole. How is this circulation consummated amidst all the disturbing effects of land and sea, mountain and valley, ascending and descending masses of air, and in the different seasons?

To determine the time of duration of the atmospheric currents it is absolutely necessary that cloud observations should be made day after day, in a continuous series. A time unit must be fixed, within which it can be assumed that the currents will not change materially. I have always chosen one-fourth day for this unit. In this manner we obtain the time of duration of each current (equal to the number of quarter days) during the year.

For every measurement of the height of a cloud I also calculated the projected velocity, in order to obtain therefrom the actual velocity; I also noted the direction and shape of the cloud, and made a small sketch of it.

In this manner an observer accumulates a multitude of data for all possible elevations, which, however, can not be utilized without further considerations. He must conceive several imaginary mean planes, extending through the atmosphere at different elevations, and assign to each the observations which were made on clouds nearest to it.

It has already been mentioned, as a result of continuous observations, that clouds occur principally in five planes. It was natural, therefore, to make use of these planes, which, in a manner, were pointed out by nature herself. The fact also proved useful that the clouds vary from one plane to another, so that with a little practice, and the aid of the projected velocities, they could be assigned to their proper planes, even when an exact measurement of their elevation was not possible.

In this manner we obtain for each of the eight principal directions and for each of the five strata, strictly speaking, only a series of velocity observations, each one of which indicates how many cubic feet of air have passed through a cross section of one square foot, or how many times 21,600 cubic feet of air have passed through this cross section in one unit of time (six hours). But the sum of the observations, each representing one unit of time, gives the time, T; the sum of the velocities gives the sum of the cubic feet of air which passed through the cross section in all the units of time, i. e., the masses of air, V; and the latter, divided by the sum of the units of time (number of observations), gives the mean velocity $\frac{V}{T}$.

The direction of the atmospheric currents is very frequently not exactly one of the eight principal directions, but is half way, or nearly half way, between two of the same. It is necessary, therefore, for instance, to compute a SSW. from the observed S. and SW. directions; a WSW. from SW. and W.; and finally from SSW. and WSW. a corrected SW. direction; and to apply this process in an analogous manner everywhere and to all directions.

By this means improved values for the duration and velocity in the eight principal directions are obtained in each of the five strata.

But the number of time units during which this or that cloud stratum was under observation is not the same in every case. In order that the times of the atmospheric currents in the several strata may be made mutually comparable, it becomes necessary to calculate their percentages for all currents by calling the period of three years 100, for instance, and determining during what percentage of time the air in the lowest stratum moved in SW., W., NW., etc., directions; the velocities, of course, remain unchanged. The percentages for the four higher strata are found in the same manner. Multiplying the times as expressed by these percentages by the always unchanged velocities, we obtain the masses, V, corresponding to the times.

If, now, the air is assumed to be of uniform density, i. e., to have a height of 8,026 meters at a temperature of 0° C., and to be divided into ten equally thick strata by means of planes which, counting from the bottom upward, correspond to an atmospheric pressure of 760 mm. multiplied by 1.0, 0.9, 0.8, ...... then the height of the barometer in the plane of the stratus clouds will be about 760 mm. by 0.94; in the plane of the cumulus, 760 mm. by 0.86; in that of the low alto cumulus, 760 mm. by 0.75; in that of the lower cirrus, 760 mm. by 0.6; and in the plane of the upper cirrus about 0.4 by 760 mm.

If coordinates be now drawn in which the equal vertical abscissas correspond to the uniformly decreasing pressure, and the horizontal ordinates, drawn for the five planes of the atmosphere, correspond to the resulting values of times, velocities, or masses (volumes); and if the

ordinate summits be connected, figures will be obtained, by the planimetric measurement[1] of which the mean values can be determined for all the five strata together, including those of the masses, because they are assumed to be everywhere subject to the same pressure. In Berlin, for instance, the following planimetric means of the times, T, velocities, V/T, and masses, V, were obtained within the limits of observation (six-tenths of the atmosphere):

*Direction of the atmospheric currents.*

| | SW. | W. | NW. | N. | NE. | E. | SE. | S. |
|---|---|---|---|---|---|---|---|---|
| T= | 18.7 | 25.2 | 21.9 | 10.8 | 4.49 | 4.26 | 5.06 | .9.69 |
| V/T= | 46.2 | 45.7 | 45.2 | 43.3 | 35.7 | 30.5 | 28 | 40 |
| V= | 864 | 1,151 | 990 | 468 | 160 | 130 | 142 | 392 |

If in the above-mentioned coordinates the lines connecting the times of the lower and upper cirrus are prolonged through the four upper squares of abscisses, under the very reasonable assumption that the ratios of the times are continued above the upper cirrus, in the highest regions, in the same manner as between the lower and upper cirrus, we obtain, for the whole atmosphere by including the contents of the upper curves, the following planimetric means:[1]

| | SW. | W. | NW. | N. | NE. | E. | SE. | S. | Total. |
|---|---|---|---|---|---|---|---|---|---|
| T= | 21 | 25.4 | 20.6 | 10.1 | 4.01 | 3.78 | 4.4 | 10.6 | *Per ct.* 100 |

These values differ but slightly from those of the former series T.

Likewise it may be assumed that the velocities of the currents are continued in the same manner above the upper cirrus, producing the following means:[2]

| | SW. | W. | NW. | N. | NE. | E. | SE. | S. |
|---|---|---|---|---|---|---|---|---|
| V/T= | 53.8 | 55.2 | 57.3 | 56 | 42.1 | 32.4 | 34.8 | 50 |

The product of time and velocity after dividing by 10 gives the following mean values:[3]

| | SW. | W. | NW. | N. | NE. | E. | SE. | S. |
|---|---|---|---|---|---|---|---|---|
| V= | 113 | 140 | 118 | 56.5 | 16.9 | 12.3 | 15.3 | 53 |

[1] Meteorol. Zeitschr., 1882, p. 355.
[2] Meteorol. Zeitschr., 1882, p. 353.
[3] Meteorol. Zeitschr., 1882, p. 356.

Therefore this hypothesis leads to the plausible conclusion that above the place of observation (Berlin) nearly as much air flows toward the north as toward the south. An accurate equalization would take place in a direction inclining about 2½° to the right of the meridian, as may be demonstrated by pointing off the mean values given above on the radial lines of a compass card, and connecting the points by a curve (see diagram, fig. 1). If a new windrose is now drawn around the center, so as to appear to be turned about 2½° to the right of the first windrose, and if the new radial lines (shown on the diagram by dotted lines) are measured, as cut by the curve, it will be found that SW = NW., N. = S., NE. = SE., i. e., that exactly as much air passes in one direction as in the other, respectively.

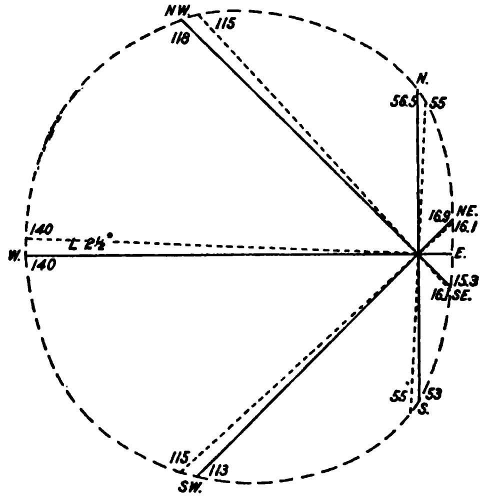

FIG. 1. Total atmospheric movement above Berlin.

This equalization of direction is of interest, for the reason that it has been found to make a regular oscillation from one side to the other in the course of the year.[1]

If curves are now also drawn for the mean values of T and V/T, as already described for those of V, and the three diagrams are compared, it will be noticed that in the direction above referred to, i. e., inclining about 2½° to the right of the true north and south line, the northerly currents flow for a somewhat shorter period of time, but quicker, and the southerly currents for a somewhat longer period of time, but slower; so that eventually as much air flows from north to south as from south to north, since the products of time and velocity are the same for both currents.

These results indicate at all events that in the very highest regions, i. e., in the uppermost four-tenths of the atmosphere, the actual conditions can not be very different from the assumed ones.

[1] Deutsche Zeitschr. für Luftschiff-fahrt., 1886, No. 4.

In striking contrast with the equalization of the north and south currents is the wide difference between those from the east and west. At Berlin, within the zone of observation (the six lower tenths of the atmosphere) nearly nine times (1151/130) as much air flows toward the east as toward the west. Within the entire atmosphere the eastward flow of air would be 11.4 (1400/123) times greater than in the opposite direction, and would require seven times (more accurately 25.4/3.78) as much time, with a mean velocity 5/3 (more accurately 55.2/32.4) greater than that of the westward flow.

When trigonometrical measurements of clouds are made at several suitable localities on our globe, it is highly probable that we shall be able to discover the laws which govern the connection between these values and the latitude. For the present we see how materially the velocity of the westerly current is impeded and retarded in the circulation of the atmosphere by the vortex motion at the boundary planes of currents flowing over and through each other.

By collecting the measured values of the times, masses, and velocities for the various atmospheric currents in the five natural strata, we obtain the mean values in five horizontal sections, which may be compared with one another and with the planimetric means, and thus we may learn in what strata the equatorial (SE., S., SW.) or the polar (NW., N., NE.) current predominates, a matter of great interest with reference to the manner in which the polar-equatorial circulation is taking place.

At Berlin, for instance, I found that equatorial winds predominate in the lowest stratum or the wind region as regards time, but polar currents in the first to the fourth stratum, i. e., from the lower clouds (stratus) to the lower cirrus, inclusive. In the fifth stratum (upper cirrus) the equatorial currents again begin to predominate, and this preponderance should, according to the above-mentioned hypothesis, continue up to the limit of the atmosphere.[1] The following table shows the percentages of duration of the two currents during a year:

| Stratum. | Pressure. | Equatorial currents. | Polar currents. |
|---|---|---|---|
| | *mm.* | *Per cent.* | *Per cent.* |
| Upper atmosphere. | 760×0 | *43* | 27.7 |
| | ×0.2 | *40* | 31.2 |
| Upper cirrus | ×0.4 | *37.1* | 34.8 |
| Lower cirrus | ×0.6 | 34.1 | *38.2* |
| Low alto cumulus | ×0.75 | 34.4 | *35.1* |
| Cumulus | ×0.86 | 30.4 | *37.3* |
| Stratus | ×0.94 | 23.4 | *42.5* |
| Wind region | ×1.0 | 45.1 | 31.8 |

Analogous results are obtained from the masses; but with these it must be remembered that the current velocity increases constantly with

[1] Meteorol. Zeitschr., 1882, page 356.

the height, and that consequently larger masses of air are propelled onward. If we call the masses of equatorial currents unity, the proportions are as follows:[1]

| Pressure. | Equatorial currents. | Polar currents. |
|---|---|---|
| *mm.* | | |
| 760×0.0 | 1 | 0.74 |
| ×0.2 | 1 | 0.90 |
| ×0.4 | 1 | 1.08 |
| ×0.6 | 1 | 1.30 |
| ×0.75 | 1 | 1.21 |
| ×0.86 | 1 | 1.28 |
| ×0.94 | 1 | 1.90 |
| ×1.0 | 1 | 0.72 |

These results of the Berlin observations agree in a marked manner with the theoretical results obtained by the great meteorologist, Ferrel. In Sprung's "Lehrbuch" of meteorology, fig. 38, page 205, is presented a scheme which corresponds to the diagram projected by Ferrel in 1858. In this equatorial winds are shown to prevail below or in the wind region of the middle latitudes, polar currents at medium elevations, and equatorial currents at great heights. But it should be remarked that, according to observations made at Berlin, the polar current develops a special intensity near its lower and upper boundaries, i. e., above the surface winds and in the lower cirrus stratum, while in its middle portions it is somewhat weakened by the influence of the lower equatorial current, which there becomes a little more pronounced. It is only at greater elevations that the polar current disappears entirely, and equatorial currents prevail exclusively in the uppermost regions.

After considering the conditions in the several regions of the upper atmosphere, as regards the times and masses of the two great principal currents, the equatorial and the polar, the question arises, what are the relative velocities with which these currents are moving onward? Here in Berlin I found the following values for the velocity of the polar currents, calling that of the equatorial currents=1:

| | mm. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Pressure | =760× 0 | 0.2 | 0.4 | 0.5 | 0.75 | 0.86 | 0.94 | 1.0 |
| Equatorial current | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Polar current | 1.15 | 1.16 | 1.18 | 1.20 | 1.22 | 1.17 | 1.06 | 1.04 |

Here our attention is at once arrested by the fact that at all elevations the polar currents move more rapidly than the equatorial ones. Observations made at other points respecting this phenomenon will have to decide whether the influence of the convergence of the meridians toward the pole comes here into play. Such influence may be suspected, for the polar currents flow unimpeded through the entire atmosphere from narrow to wide spaces; the equatorial currents, on the contrary, press into spaces which become more and more narrow,

[1] Meteorol. Zeitschr., 1882, p. 356.

and, by vertical motions, are compelled to perform work by which their velocity is diminished.

Thus far we have considered the question of atmospheric circulation as presented by the means for the year. The observations for the different seasons may be treated in precisely the same manner, and utilized in all directions for purposes of investigation. Thus, for instance, the durations of the equatorial and polar currents at the different elevations can be compared with the planimetric means, and the seasonal differences investigated which such comparison may disclose. At Berlin it was found that the main polar current, which in the annual mean occupies the middle portion of the atmosphere, undergoes decided changes of position in the course of the year. It flows at its normal height during summer and winter, rises above the upper equatorial current in the fall, and sinks below it in the spring. Whether this is a mere local occurrence at Berlin, or whether it is a more general and widely distributed phenomenon, can only be decided by measurements made at a number of suitable places. Should it be characteristic of the middle latitudes of the entire northern hemisphere—which I consider probable from the grandeur of the phenomenon—it would be in remarkable harmony with certain experiments which visibly demonstrate how the movement of the atmosphere is influenced by the shifting of the belt of calms, and how the circulation of one hemisphere affects that of the other.[1]

The investigation becomes still more interesting if, entering into further details, we study the atmospheric currents above the different surface winds at all seasons of the year.

By having noted the wind in connection with each cloud observation, we are enabled to combine all cloud conditions, i. e., the times, masses, and velocities of the currents, above each of the eight principal currents, at the different heights, and in every season of the year.

In order that the currents prevailing at different elevations may be compared with one another, it becomes necessary to reduce the durations of the various currents to the duration of the surface wind, and if we then determine the planimetric mean for each current, we are able to comprehend the entire series ("constitution") of the motions of the air above each surface wind. We may determine, for instance, at what height each current is most in excess of the planimetric mean. By using this method with all winds, I recognized the remarkable system of circulation, showing that with every surface wind there is, in the highest regions, a current in the opposite direction. I could distinctly trace the ascending and descending currents, while the surface wind was turning through the points of the compass to the right or to the left. I saw how the lighter winds, the southerly, for instance, when displaced by descending SW. winds, rose abruptly to the highest elevations at

[1] Meteorol. Zeitschr., 1884, p. 229.

all seasons of the year, and there reached their greatest excess over the planimetric mean. I could see that the equatorial and polar currents in the regions where they prevail, as a consequence of the great system of atmospheric circulation between equator and pole, and where they become perceptible through the increase upward of the durations (frequency), exhibited this increase *in all winds*, and so independent of the latter.[1]

In investigating the reciprocal effects of the barometric maxima and minima upon the polar equatorial circulation, we determine the durations, masses, and velocities within the limits of the cyclonic and anticyclonic circulation, for each octant of the same, in each of the five cloud strata and in the wind region.[2] As a matter of course, the only time that can be used as a time unit in this connection is that of the synoptic weather maps—that is to say, usually the morning observations.

But as cloud observations are not equally frequent in the several octants, while the time is the same everywhere during the year, it is here, too, necessary to calculate the values in each octant in percentages.

Aside from special results, these investigations showed in general that the opposite octants of the barometric maxima and minima produced analogous results everywhere. It was further shown that, while wind movement in cyclones and anticyclones is generally in accordance with Buys-Ballot's law, the great currents of the polar-equatorial circulation, in passing through these whirls in the higher regions, experience only a deflection in a cyclonic or anticyclonic sense. The path of these currents, looked at from the pole, is bent concave within the cyclone, and convex within the anticyclone, and if both lie side by side in a suitable direction the air will describe a winding path.

In the investigations heretofore described, it will be necessary to utilize as much as possible observations made at places where the movements of the air are least interfered with. On the other hand, a series of other but equally important observations will have to be made in the vicinity of mountains, as experiments have shown that great elevations of the land produce very material and far-reaching effects upon the movements of the air.

With these suggestions, I beg leave to close this paper, partly in order not to exceed the limit allowed me, and partly, also, because I have deemed it advisable to mention principally only those methods of investigation in which I have had some personal experience, and by which I was able to obtain results in one direction or another.

Further and widely distributed observations will indeed have to be made and studied in order to obtain a picture of the great system of atmospheric circulation and to recognize the laws according to which it is consummated.

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[1] Zeitschr. für Luftschiff., 1892, pp. 226, 253, 281.

[2] Meteorol. Zeitschr., 1886, p. 392; 1887, p. 214. Arch. d. deutsch. Seewarte, 1888, No. 5.

## 22.—CLOUD PHOTOGRAPHY.[1]

M. ALFRED ANGOT.

The study of clouds is one of the most interesting features of meteorology. Their forms and their movements have a certain relation to weather changes, and not infrequently permit them to be announced a long time in advance. On the other hand, the determination of the altitude and the velocity of the clouds is the only means in our possession, outside of balloon ascensions, for obtaining a knowledge of the direction and velocity of the upper atmospheric currents.

But this study offers the greatest difficulties. It is impossible, indeed, to describe the aspect of the clouds in a manner precise enough to enable one to form even an approximate idea of them. A drawing is equally powerless to present their complex appearance and rapidly changing form. The employment of photography gives, therefore, an absolute method of fixing the exact aspect of the sky at any given moment; but in the employment of that method there are substantial difficulties, particularly as regards the white and very delicate clouds, as cirrus and cirro-cumulus, which are the most elevated of all, the most varied in form, and the most interesting for meteorologists. We know in general that the blue acts nearly as the white light on ordinary plates, particularly if the white is of slight intensity and the blue diluted with white, which is precisely the condition with cirrus; we obtain, then, only a uniform sky if we employ ordinary photographic methods. It is necessary, therefore, to seek to subdue or extinguish the photogenic action of the light of the sky, at the same time preserving that of the clouds in sufficient intensity. We can arrive at this result in several ways. The most simple consists in interposing a yellow color-screen between the sensitive plate and the light rays; the blue light of the sky containing little or none of the yellow rays is almost completely arrested, if the color of the screen is sufficiently deep; on the other hand, the clouds act on the plate through the fraction of yellow light that they may contain. This is the method that was first employed. M. Hildebrandsson, professor at the University at Upsala, published in 1879 quite good photographs of the clouds obtained in this manner. He used as a screen a small cylinder of glass with parallel faces containing a solution of gamboge added to a little sulphate of quinine. Inasmuch as the ordinary photographic plates are only very slightly sensible to the yellow rays, it is necessary to give a long exposure, which is not always possible for clouds. M. Garnier, of Boulogne-sur-Seine has employed an analogous method by which he has obtained

[1] Professor Angot's MS. was accompanied with twenty-five splendid silver-print photographs of typical cloud forms. Owing to the expense of reproducing them satisfactorily, they have been omitted from the printed paper. The photographs have been placed in the library of the U. S. Weather Bureau.—[EDITOR.]

excellent prints; unfortunately, he has not published his method, under the pretext that the processes to which he had recourse are too complicated to be described in a manner such that others could use them.

M. Riggenbach, professor at the University of Basle, has indicated another method based on the fact that the blue light of the sky is partially polarized, particularly at 90° from the sun, while that of the clouds does not present any trace of polarization. In looking at the sky through an analyzer, which we turn in the ordinary manner, we in effect extinguish a considerable portion of the rays emitted by the blue sky without proportionately diminishing the light of the clouds, the contrast is increased, and we are thus able to obtain excellent prints. As an analyzer we may place before the objective either a Nicol prism or a black mirror inclined at the angle of total polarization, this apparatus being carried by a frame which permits of its being turned around the optical axis of the objective. One great inconvenience of this method is that it is not equally available for all portions of the sky, the degree of polarization of light varying greatly according to the direction. Further, we can scarcely employ the Nicol prism, as it greatly reduces the field of view, and the black mirror placed before the objective makes the orientation of the apparatus very difficult. However, this method in the hands of M. Riggenbach has given very good results, especially when operated on the summit of high mountains where the sky is generally of a very deep blue, which increases the difference between the photogenic action of the sky and of the clouds.

A last method, which has been equally employed by M. Riggenbach, is the following: No special artifice is employed, and we simply photograph the sky, but with a very small diaphragm and an exposure so exceedingly short that scarcely any image will appear during development; and so that only after fixing, the image of the clouds may be slightly visible. The plate is then intensified by one of the most energetic processes (bi-chloride of mercury and Schlippe's salt). This process is not to be recommended, it is dangerous; for Schlippe's salt is difficult to keep and ordinarily strongly colors the negative brown; often, even, it produces metallic "marbling." Moreover, the intensification, particularly if energetic, always veils the image and diminishes the detail.

After many trials, I am of opinion that the first is still the best and the most simple of all these methods—that is to say, the employment of color screens, provided that one uses at the same time appropriate plates.

For screens I take small square troughs with parallel sides of glass, which one can make himself or procure easily at an optician's, and within which a suitable colored liquid is placed. The trough is fastened by means of bands of india rubber to a piece of cork with a circular opening in its center, which is held to the tube of the objective by friction.

The troughs which I employ are from 6 to 7 mm. in thickness, inside measurement. The colored liquid—the most simple to employ, and which gives at the same time excellent results—is a solution of bichromate of potash to which has been added several drops of hydrochloric acid. It is advisable to have three troughs containing solutions of different strength—a solution of 10 in 100 (prepared by heating to a little above 20° C.); a solution of 5 in 100, and a solution of $2\frac{1}{2}$ in 100. The screen of the deepest color should be reserved for photographing the lightest and the less luminous clouds, when the sky is not a pure blue, but diluted with white. The medium screen answers ordinarily; and finally we take the lightest for photographing the large round white clouds (cumulus) of well-defined form, generally very bright, and which are projected against a sky of ordinary intensity.

We can evidently replace the troughs by plates of yellow glass, cut with parallel faces. But all glass is not suitable; it is necessary, consequently, to test it thoroughly before discarding liquid screens. However, as the use of colored glass would be more convenient than the liquid screens, I intend to study the question, with the cooperation of glass manufacturers, with a view of ascertaining if it is not possible to manufacture suitable glass which can always be exactly reproduced.

It is necessary to employ, simultaneously with colored screens, gelatino-bromide plates specially sensible to green and yellow rays. One can prepare these plates himself, but as the purpose of my researches has been to indicate simple means that everybody can easily apply, I have tried a certain number of brands of plates called *Orthochromatic* or *Isochromatic*, which can be found in the trade. Two of these brands suit perfectly, and give wholly equivalent results as to rapidity and vigor. These are the *Lumiere* plates, sensitive to yellow and green (Series A), and the Edwards plates.

On the contrary, the orthochromatic plates of Monckhoven, Attout-Tailfer (green or yellow seal), and Lumiere plates, sensitive to yellow and red (Series B), have not given me good results. It is not to be understood, of course, that these plates may not be good for other purposes, but simply that they are not suitable for this particular sort of work.

I shall add that there is no need to fear too rapid deterioration in these plates. I have had occasion several times to keep for more than three months an opened box of Lumiere plates, sensitive to yellow and green, without the last appearing in the least inferior to the first.

There is no special formula to be followed in the development. I have employed indifferently iron, pyrogallic acid, hydroquinon, and para-amidophenol. Whenever the clouds taken simultaneously on the same plate have nearly the same intensity, we may employ an automatic developer. I have made use (for more than 6 months from the same bottle) of the developer sold by MM. Poulenc under the name of *Iconophile*, and which appears to have as a base hydroquinon and eosin. If, on the contrary, there are at the same time several species of clouds

of very unequal intensity, there is an advantage in developing with pyrogallic acid (method of M. Londe), proceeding with caution and employing at the first only a very little bromide and pyro until all of the details appear, so as to diminish the contrasts as much as possible. This precaution is particularly useful if there exist in the sky at the same time cirrus and cumulus, for with an automatic developer it will be almost impossible to obtain sufficient intensity for the cirrus without entirely obscuring the cumulus.

In operating as I have explained, one can obtain without any difficulty even the lightest clouds. The duration of the exposure is necessarily variable according to the objective, the state of the sky, the hour of the day, etc. With a Prazmowski panoramic objective of 160 mm. (6.3 inches) focus and diaphragm $\frac{f}{30}$, one can photograph the most delicate cirrus by employing the deepest color-screen (bichromate 10 in 100) with an exposure of half a second. With a Zeiss objective of 196 mm. (7.7 inches) focus (Series III*a*), diaphgram $\frac{f}{18}$, and medium color-screen, it suffices, for ordinary clouds, to expose one-thirtieth or one-fortieth of a second.

I hope that these instructions will appear precise enough to induce a great number of amateurs to attempt the photography of clouds. The only precaution to take, in order that these photographs may be utilized, is to note exactly the day and the hour when they have been taken; also the direction which corresponds to the center of the plate (N., NE., etc.). It will frequently be interesting also to take two photographs successively at three or four minute intervals without changing one way or the other the orientation of the camera. We will have thus the measure of the displacement of the clouds and the manner in which their forms are modified.

If some would undertake this study, it would be easy to gather in a short time a large collection of the forms of clôuds, particularly the clouds composed of light and delicate filaments, feathery structures or plumes (cirrus), and the fleecy clouds (cirro-cumulus) which accompany and often announce the changes of the weather. The comparison of these forms with atmospheric conditions will certainly give results of the greatest interest, and also lead to new progress in the science of the weather.

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WEATHER BUREAU.

# REPORT

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